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The Contents of

Reliability Abstracts and Technical Reviews

The first section of *RATR* contains bibliographic citations, abstracts, and reviews. The items (each identified by an *RATR* accession number) are arranged in subject categories based on the first two digits of the codes developed by the American Society for Quality Control. The complete listing of these ASQC codes appears on the inside back cover. Examples of citations of reports, journal articles, and conference papers are shown below. The principal subject field of the item (and therefore the category in which the item appears in the journal) is indicated by the first ASQC code number; related subject fields are indicated by additional code numbers. The appearance of a *TAB, STAR,* or *IAA* accession number indicates that the item has been announced in, respectively, *Technical Abstract Bulletin, Scientific and Technical Aerospace Reports,* or *International Aerospace Abstracts.*

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EXAMPLES OF CITATIONS IN *RATR*

***RATR* ACCESSION NUMBER** → R68-12733 ASQC 844; 413 ← **ASQC CODES**

General Equipment Company, Banville, Calif. ← **CORPORATE SOURCE**

TITLE → **RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT**

AUTHOR → John A. Doe 23 Sep. 1966 ← **PUBLICATION DATE** 27 p refs

CONTRACT OR GRANT → (Contract NAS15-13411)

REPORT NUMBER → (TR-3; AD-629305; N67-15098) ← ***TAB* AND *STAR* ACCESSION NUMBERS** CFSTI: HC $2.00/MF $0.50 ← **SALES AGENCY AND PRICE**

***RATR* ACCESSION NUMBER** → R68-12739 ASQC 814 ← **ASQC CODE**

TITLE → **SEMICONDUCTOR RELIABILITY**

Joseph A. Smith (Eastern University, Arlington, Penn.) ← **AUTHOR AND AFFILIATION**

JOURNAL REFERENCE → *Electric Journal,* vol. 8, Apr. 1966, p 478–492.

(A67-12569) ← ***IAA* ACCESSION NUMBER**

***RATR* ACCESSION NUMBER** → R68-12765 ASQC 773; 221; 823 ← **ASQC CODES**

TITLE → **TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES**

Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.) ← **AUTHORS AND AFFILIATIONS**

CONFERENCE OR SYMPOSIUM REFERENCE → *Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p.*

Available from Assoc. of Reliability Eng., New York: $1.00 ← **AVAILABILITY AND PRICE**

***IAA* ACCESSION NUMBER** → (A67-12407)

VOLUME 8 NUMBER 1

Reliability Abstracts and Technical Reviews

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JANUARY 1968

80 RELIABILITY

R68-13547 ASQC 802
Battelle Memorial Inst., Columbus, Ohio.
RELIABILITY PHYSICS NOTEBOOK
J. Vaccaro, ed. (Rome Air Develop. Center) and H. C. Gorton, ed.
Oct. 1965 321 p refs
(Contract AF 30(602)-3504)
(RADC-TR-65-330; AD-624769; N66-15682) CFSTI: HC $3.00/MF $0.65

The results of physical and chemical investigations on basic mechanisms and processes in materials which cause or contribute to degradation, aging, and failure of electronic devices are summarized. Data is presented, in practical form wherever possible, for use by design and test engineers concerned with the assessment, prediction, and improvement of the reliability of solid state electronic devices. Techniques and procedures for obtaining data on specific part types and for applying such data to accelerated testing, screening, and reliability prediction programs are discussed. Format of the report is designed to facilitate periodic revision and inclusion of results of future investigations in basic failure mechanisms in electronic materials. TAB

Review: This is a six-section book presumably (from the title) dealing with all of Reliability Physics. In the Foreword we find out that it is limited to reliability physics of electronic parts only. The overall impression is that of a superficial, long-winded treatment of the theory and a good collection of physical data. Sections 3 (Physical Properties of Materials and Processes Pertinent to Reliability Physics), 5 (Reliability Screening Procedures), and 6 (The Use of Statistical Methods in Reliability Physics Experiments) are the strongest sections in the book. Sections 1 (Mathematical Models in Reliability Physics) and 4 (Accelerated Testing) are weak. Section 2 (Aging and Failure Mechanisms) uses over half its pages for introductory material and poorly utilizes the remainder. In Sections 1 and 4 the elaborate discussions of the Arrhenius and Eyring equations are the largest sources of discontent. Most of the rest of the discontent comes from indiscriminate acceptance of items from the literature even though some are wrong. The basis for these general comments is given below in a section by section analysis of the Handbook.

Section 1: The material in this section is a conglomeration of material from the literature and exhibits the indiscriminate examination of that literature. Many of the arguments presented in this section are sophistry (unsound or irrelevant arguments which have the appearance of astuteness) in essence if not by intent. The distinction between empirically based models and theoretically sound models in this section is not a clearcut one, but is a matter of degree. In some cases models can be asserted to be theoretically sound or exact if they are considered to be definitions of one of the parameters or concepts involved in the equation. Many of the theoretical equations in physics are of this type. (For example, the equation E=IR for resistance is exact because it is the defining equation for R. Ohm's law can then be stated, as R is a constant over a wide range of voltage and current for many materials.) Often a model which is called theoretically sound is an expansion of an earlier model by means of a few other assumptions and the following through on their logical implications. It is often worthwhile to distinguish in a theoretical development between those assumptions which are true by a definition of one of the parameters or concepts involved, and the assertion which usually suggests that the parameter is a constant in many physical situations. The more a model is based on earlier more basic models (i.e., the fewer parameters there are which are evaluated from the data), the more difficult it usually is to evaluate the unknown parameters in the model without data. For complex engineering systems such earlier more basic models are at best only a rough guide to the kind of behavior that might be observed. When that behavior is not observed, the two extreme choices are to disbelieve the interpretations of the observations or to consider the model as inadequate. Specific examples of the difficulties in this section are:

1. Equation 1.2 (p. 1-2) is incorrectly stated and incorrectly described. The first term on the right-hand side is unnecessary or else the second sum should be for $i \neq j$. The equation is true as written only if all of the x variables are completely linearly correlated; to be correct in general the $\sigma_i\sigma_j$ should be replaced by σ_{ij}^2 or by $\rho_{ij}\sigma_i\sigma_j$.
2. It is said (p. 1-2) that "the principal shortcoming of such models is that they . . . are generally not used to determine how long a device will operate satisfactorily." The models, of course, can be used in this way and the fact that people do not so use them is not necessarily a shortcoming of the models, but perhaps of the people who use them.
3. It is said (p. 1-4,5) that "...models giving population characteristics would necessarily be different from those that hold for an individual device." It is not at all obvious why this is necessarily the case.
4. The subsection (p. 1-6) on "A Mathematical Derivation of the Arrhenius Model" is not helpful in visualizing the application of the Arrhenius equation to an engineering system. The derivation depends on many analogies and assumptions which are scattered throughout the derivation. The exercise is more an interesting

hunting expedition than it is a rigorous derivation. As such it is not likely to be useful in determining the behavior of electronic components.

In this connection the term Reliability Physics is the name given by engineers to the more fundamental work they do. Physics can be considered to encompass everything that uses physical science, but this is not generally done. From a fundamental physicist's point of view, for example, most Reliability Physics is still gross engineering. This is not to say that it is not valuable, but merely to put perspective on the term.

5. The implication (p. 1-13, 21, 23) is unfortunate that true acceleration (for temperature) is a situation wherein the Arrhenius equation applies. One might wish to refer to such a situation as true Arrhenius acceleration, and then to reserve the term true acceleration for something more general. A very reasonable concept of true acceleration is essentially the situation wherein a monotonic transformation of the time variable is all that is necessary to make the accelerated situation equivalent to the unaccelerated one. This is so regardless of whether or not there is a single dominant failure mechanism. Basically what one is after is to answer the question, "Is the device acting as if time were speeded up or is the behavior quite different from the usual?"

6. The derivation (p. 1-18) which attempts to duplicate the Eyring derivation for a simple chemical reaction by applying that derivation to a complicated system such as an electronic component has several fundamental difficulties, not the least of which is the lack of explicitness at critical points. If potential energy is the actual physical potential energy of all of the particles with respect to each other due to the interparticle forces, then one would need to have the number of dimensions be at least three times the number of particles present. The nature of the resulting n-dimensional surface is virtually impossible to visualize (e.g., it may have many interconnecting channels) and the very simple example of a ball rolling in a channel is inadequate and misleading for the complicated case.

Another difficulty is that Fig. 1.2 assumes reversibility up to the peak. This is likely to be physically unreasonable for the component as a whole. The assertion that the entire component can be divided into a number of subcomponents that are small macroscopically but large microscopically does not apply to this situation because of the play on the words macro- and micro-scopic; i.e., since we are identifying the coordinates of all atoms, the whole component is a microscopic situation. Furthermore, electronic components which are never acted upon by external forces are useless. All electronic components (by definition) are acted upon by electric fields when in use and these electric fields are explicitly omitted from consideration. In short, this section is trying to apply tools which are completely out of place at this time for the job at hand.

7. The application (p. 1-21) of the Arrhenius equation to constant hazard rate is a contrived derivation. The introduction of the Arrhenius equation is irrelevant and unnecessary. The answer is the same in the exponential case regardless of what model is assumed for the rate. (This is a further example of the sophistry in this section.) A similar discussion (p. 1-22) for the Weibull distribution is again pointless. It is stated: "...under one additional assumption the Arrhenius model can be applied to Weibull-distributed failure data." This one additional assumption (which it is easy to infer is minor, but it really is not) is that the shape parameter be constant and known. But when this is done the Weibull distribution converts with an extremely simple time transformation into the exponential distribution. Furthermore, the basic problem being attacked, but not explicitly pointed out, is that the Arrhenius equation deals with only one parameter, viz., a rate, and if the distribution of concern has more than one parameter there is a dilemma about the one to which the Arrhenius equation applies. There is certainly no law that says the Arrhenius equation cannot apply to the Weibull shape parameter.

8. The summary (p. 1-24) contains only discussion of new material rather than summarizing the old.

9. Even though the authors put the word derivable in quotes, the machinations (p. 1-25) to get from the formula for statistical mechanical entropy to the so-called Delbruck model are grossly concocted. Using the same techniques one could derive any equation from the form that a = b by the simple expedient of letting a be anything you wish and b be anything you wish.

10. Equations 1.84 and 1.85 (p. 1-26) are asserted to be equivalent as shown in Ref. 13. Unfortunately Ref. 13 is completely in error in this regard. It is easy to show by simple algebra that if the property whose rate of change is given by Eq. 1.84 is considered to be a continuous variable, then one cannot use the time-Temperature parameter (tTp). The tTp cannot be used at all as a theory of cumulative damage or of cumulative change. The derivation can be correct only where it is possible to assign the value of unity to the change in the property whose rate is following the Arrhenius law.

Section 2: There are 56 pages of text in the section. Over a quarter of these are used for material which belongs in an introduction to solid state physics; the rest of the first half is used on an elementary description of device construction. This is an unbalanced emphasis for a Reliability Physics Notebook. Of the remaining half, over one quarter is spent on thin film resistors. This does not leave much room for the real meat of aging and failure mechanisms of the remaining electronic parts. For example, there is no mention of thick film resistors or thick film technology in general, and these were important in microelectronics even when the text was written. The material which appears is generally adequate, aside from emphasis (number of pages) wherein a topic like Corrosion at the Conducting-Wire Silicon Interface is given very short shrift. Two difficulties that do appear in the text are the following:

1. There can be no rigid distinction in general between failure modes and failure mechanisms (p. 2-2). One man's failure mode may be another man's failure mechanism, depending on the level at which the system is being observed, just as a lieutenant's strategy may be a colonel's tactics. Failure mode is an observation about the system; failure mechanism is the explanation at a more detailed lower level for the failure. Even at the electronic parts level (at which point there are not many lower levels) there is some ambiguity in the two terms. For example, the considerations of basic causes of failure are at a materials level—not at the level of quantum mechanics.

2. The derivation (p. 2-47) of the time-Temperature parameter from the Eyring equation is incomplete for the general case. See comment 10 under Section 1. In the context of the application suggested in the text, the derivation is in error as can be determined using elementary algebra.

There are 85 references for further information which can be of value for anyone who wishes to pursue any one of the subjects in depth. The discussions in the text are necessarily brief, but can be used as reference material for someone not familiar with the subject.

Section 3: The authors have chosen well in including data for the limited space. A spot check turned up no discrepancies and these data can be very helpful to engineers. Readers may be interested in the general collection of properties to electronic materials being published by Hughes (specific papers of which are referenced in the text) and the Air Force report on Integrated Silicon Device Technology, Volume 5 (Physical/Electrical Properties of Silicon).

Section 4: This section gives good advice and has severe deficiencies at the same time. The suggestion that after a complicated analysis a final correlation plot be made, namely plug the original data into the final formula and compare it with the calculated curves, is excellent advice; although it is usually a rather discouraging experience because of the large scatter that is readily observable. The criticism of this section deals largely with the step-stress testing and with the Arrhenius/Eyring equations as a basis for accelerated testing. The cookbook **procedures on step-**

stress testing are not careful to point out which steps in the recipe are important and which steps are not too important and why. Specific examples are given below.

1. The term step-stress as used in the literature. and here is ambiguous. It is ambiguous because the analysis to be used depends on the height of the step (change in stress) and tread (time duration). The term step-stress can refer to any of three situations: large, medium, and small steps.

(a) Large steps—The steps are presumed high enough that the time which would have been required (at the last stress—the one at which failure occurs) to accumulate all of the damage done at the lower steps is negligible (an easier but less explicit statement is that the cumulative damage up to the last stress is negligible).

(b) Small steps—In this case the steps are small enough that in the analysis one can presume with negligible error that the stress is steadily increasing.

(c) Medium steps—Neither the assumption in (a) nor in (b) is valid. The cumulative damage of previous steps must be taken into account, but the steps are not small enough that the stress can be considered continuously increasing.

In order to be able to refer reasonably to these three cases later in the review the following terminology is used: large/step-stress, medium/step-stress, and small/step-stress. The size designations are not absolute but are in relation to what is considered negligible for the situation at hand. Large/step-stress tests are analyzed as if they were constant-stress tests at the last stress. Parts which are very expensive or otherwise difficult to come by or test are often tested in this way. Medium/step-stress is apparently the case treated in the text. Small/step-stressing is analyzed exactly the same as progressive stressing. The only difference in analysis between medium/step-stressing and progressive stressing is the summation sign instead of an integral.

2. It is easy to infer from the text that there are two different kinds of truly accelerated testing (see item 5 under Section 1 of this review and p. 4-1). One suggests that true acceleration exists when the Arrhenius equation is obeyed. The other suggests that true acceleration is the situation wherein the short time at the high stress produces the same effects in the component as a longer time at usual stresses. The latter is a quite reasonable concept for true acceleration but one can have it without having Arrhenius acceleration. It is likely that one can also have Arrhenius acceleration without having true acceleration.

3. The phrase (p. 4-2) "...a statistically significant number...on life test..." and similar ones in the text (e.g., p. 4-5) have no meaning. The reason is that statistics can handle a sample of any size and in particular it can handle small samples. What is probably meant when this phrase is used (and it is used often elsewhere in the literature) is that a sample should be large enough so that the results of the statistical analysis will have engineering significance. Use of the phrase statistically-significant without criteria for determining such significance is without meaning.

4. The questions (p. 4-3) to be asked for constant-stress testing are good.

5. In the paragraph dealing with reversible and nonreversible changes no account is taken of hysteresis which is an awkward cross of the two; as long as one is not confused by labels there is probably no difficulty.

6. The choice of the number of stress levels is rather briefly discussed and five is suggested as a somewhat arbitrary but reasonable minimum. In view of the scatter that often occurs it will take many more than five stress levels if you wish the data points per se to determine what kind of lines should be drawn. If all that you wish is to say whether the data are reasonably consistent with lines which you may draw, then not even five points are necessary. In reading the text (which is necessarily brief) it is important to keep in mind these two extremes of viewpoint in data analysis. Often one wishes to do both at the same time and this is where difficulties arise in determining just what has been proved. Most data have so much scatter that they can support several reasonable but different hypotheses equally well.

7. "To date, well defined statistical procedures for analyzing these data using the Arrhenius and Eyring models are generally nonexistent," is a statement (p. 4-6) which still holds and should not be forgotten even though it takes up a very small space in the text compared to the many pages devoted to analyses using these equations.

8. The sub-section on step-stress accelerated testing (p. 4-9) repeats some of the errors and misleading statements of Dodson–Howard (the given reference). These misleading and erroneous statements concern the interchange of the roles of stress and time in step-stress testing in contrast to constant-stress testing. That this interchange is utter nonsense is best illustrated by the assertion (p. 4-9) that "...parameter degradation...at a given point in the stress domain is independent of the particular combinations of stress and time used to arrive at that point." The easy comparison of taking two special paths shows the obvious error: the first path follows the stress up from zero to the given value (at $t=0$) and over in time; the second follows time over to the given value (at $s=0$) and then up in stress. Except for the case where the simple stress-strength model holds and time is irrelevant in determining damage, the quoted remark is patently false. In *running* a step-stress test the fact still remains that the time variable is very special. This will be true as long as the endurance of a part is a random variable. In a progressive-stress test (or small/step-stress test) it is true that the end of the test can be marked by the stress at failure as well as the time to failure; but this is true only because the two are related by the method of running the test. This particular stress at failure does not have the same significance as does the strength in the simple stress-strength model of failure. In the discussion on progressive stress (p. 4-16) a similar statement to that quoted above is made and is just as fallacious as it was before.

9. The discussion of the scale to be used in laying out equal steps (p. 4-11) is completely inadequate. For example, the claim that the scale for thermal stress should be $1/T$ because temperature (T) appears that way in the Arrhenius equation is just as foolish as saying that it should be $\exp(-1/T)$—it also appears that way in the Arrhenius equation. It is also inadequate to assert that stress-steps should be spaced such that the reciprocal temperature differences are equal. A much more helpful statement of the situation is to use a function of the 'stress' for the scale such that an optimum balance is struck between the following considerations:

(a) ease of adjusting the 'stress,'
(b) reasonableness of the resulting data curve (most engineers prefer a straight line),
(c) the tractability of the data analysis,
(d) minimization of uncertainties in the final parameter estimation.

It should be noted that as long as the 'stress' is increased at each step there is some function of the stress (however peculiar it might look) such that the 'stress'-steps are equal.

It is interesting to note that while a great point is made that stress-steps should be equal in $1/T$ on the above page, it is not $1/T$ that is linearly increased in the progressive stress but T itself (p. 4-21). If $1/T$ or $\exp(-1/T)$ had been linearly increased the analysis would have been much more tractable. The important thing to remember in selecting the relative size of the steps is that there is nothing inherent in step-stress testing that determines the relative size; sizes are determined by what the experimenter hopes to accomplish.

10. "...to select the magnitude of the stress step such that significant parameter degradation will result before the stress limits are exceeded," is good (p. 4-11). As Dodson and Howard have pointed out, where the reliability of the items is very good it may not be possible to adjust the slope of the step-stress curve to achieve this end. Instead of "magnitude of stress step" only, one should include the slope of the stress step since the ratio of

time interval to stress increment is important.

11. While lip service is paid earlier to the randomness of results in step-stress testing, none of it is brought out in most of the analysis. For example,

(a) the total damage-to-failure (called "endurance" here for short) may well be a random variable for various members of a population, and,

(b) the rate of degradation may be a random variable.

It is not pointed out how to calculate the degradation rate in the text. Usually one takes the median-time-to-failure and asserts that the rate is 1/median-time-to-failure without regard to the randomness involved; then the endurance is considered to be a random variable (see #12 below).

12. "Two major assumptions are critical to the analysis of step-stress test data." It is easy to infer from this statement that two assumptions which follow it are essential for the analysis of step-stress data, whereas they are not. An adequate statement of the situation is: in order to relate constant-stress and step-stress data *some* theory of cumulative damage must be available. It is not necessary that it be a linear theory. In the field of fatigue, for example, there are a great many theories of cumulative damage, many of which are not linear. The linear theory of cumulative damage is most often assumed, especially in electronics, because it is extremely tractable and because the data usually have so much scatter that a more accurate theory would contribute very little to better results. The linear theory of cumulative damage is defined by one assumption: the rate at which damage is accumulated is 1/median-time-to-failure at the stress under consideration. There are several corollaries which follow from this assumption and which are often (but improperly) stated as additional assumptions:

(a) the rate of doing damage does not depend on the amount of damage already done;

(b) the order in which the 'stress' levels are applied makes no difference;

(c) the total damage is the simple sum (integral) of the damage done at each 'stress' level;

(d) the rates of doing damage are independent of each other for different 'stress' levels;

(e) the median endurance is unity.

13. The phrase (p. 4-13) "...the state of a device at a specified damage (degradation) level is independent of how that level was obtained..." is not at all clear since the degradation level is essentially a measure of the state of a device.

14. (p. 4-14) To show the extreme arbitrariness of the so-called generalized Eyring equation for nonthermal stresses, and to show further sophistry as in Section 1: "For dielectric material, it is generally assumed that, for fixed temperature, stress is given by the logarithm of applied voltage, V." Few will recognize this as what they have generally assumed. The only reason for assuming it here, of course, is that when it is plugged into the "generalized" Eyring formula, the usual power law comes out.

The power law for capacitors cannot be *derived* from the Eyring equation (p. 4-50) and reference 11 of the text is still more contrivance. The power law, as is reasonably well known, is very generally used but rather inaccurate.

A much better approach and one which would have eliminated the sophistry from both the above occasions would be to start with the empirical power law and to show what kind of 'stress' must be assumed in the "generalized Eyring equation" to give that result.

15. Stepping, or making progressive, more than one stress at a time is not considered. This technique can be very useful although more difficult to relate to constant-stress testing. It is, however, more likely to uncover potential failure mechanisms.

16. The criticisms applicable to the sub-section (p. 4-20) on progressive stressing are essentially the same as those given for the sub-section on step-stress testing.

17. There is much tedious repetition of analyses within the section for the different kinds of data. Much of the material on the Arrhenius equation in this section is very similar to that in Section 1.

18. In connection with the assumptions on the Arrhenius analysis (p. 4-24), the first one states that degradation in performance is assumed to be a linear function of time. It is more adequately stated as "the measurable performance parameter is a monotonic function of time." If this is the case, then it is obvious that there exists a transformation of the measured performance parameter, or of the time, or of both, such that a linear function will result. If the measured performance parameter is not monotonic in time, there are grave difficulties with the Arrhenius equation in the first place (degradation need not be monotonic). To apply the Arrhenius equation it is not really necessary that linear degradation be assumed. It is merely necessary that a one-parameter function be available and that this parameter have the Arrhenius behavior. Any least-squares fitting on the Arrhenius plot should of course be a weighted least-squares analysis.

19. In this sub-section on analysis (p. 4-29) there is again confusion about the definition of true acceleration. See point 5 under Section 1.

20. The extension of the Arrhenius equation to include nonthermal stresses (p. 4-32) is of course completely arbitrary just as it is in the Eyring equation.

21. The discussion on the Eyring equation (p. 4-33) as a basis for accelerated testing is quite repetitious of that for the Arrhenius equation. There is some unjustified concern about the fact that the temperature appears outside the exponent in calculating the acceleration factor. The variations in this factor are usually negligible and are largely ignored (properly) in the rest of the text.

22. The attempt to derive an Eyring formula for a component (p. 4-35) is adapted from Section 1 (more needless repetition). See point 6 under Section 1.

Section 5: This is generally a good section and will be helpful to engineers who are newly confronted with the problems of screening. It deals quite reasonably with the inherent problems involved with screening, and with the fact that we could do much better if we knew more. The work reported by Ryerson on screening for satellite parts is not referenced but can be helpful. Some detailed comments follow below.

1. The quibble in the introduction (p. 5-1) about the difference between reliability-screening and quality-control is unfortunate. One purpose of virtually all quality control is to remove in advance those items which are likely to cause failure in the finished device. Surface finish, for example, affects life of moving parts but is considered a quality aspect. It is often more helpful to consider reliability screening as an extension of ordinary quality control rather than as something quite different from it. The text also asserts that acceptance sampling is not 100% inspection whereas reliability screening is 100% inspection. While the latter is true by definition, obviously there exist many situations in acceptance and other quality control procedures where 100% inspection is used. One purpose of all quality control and reliability work is to assure that the devices will work both initially and for some reasonable time.

2. In the sub-section (p. 5-4) on interference between stress and strength distributions it is assumed that the stress and strength are statistically independent (unfortunately, the assumption is not stated). While this may usually be the case, it is sometimes not. For example, high voltage may be correlated with high temperature in the part which in turn would be correlated with a lower strength of the part.

3. In many applications one does not know the parameter values of the distributions exactly but only from a small sample. The probability density function may not be well known very far out on the tail of the distribution where in fact the problems lie. This will cause the method of analysis to be much more complicated than indicated in the text.

4. (p. 5-12) It is not obvious why a bell-shaped distribution of

strength should have a constant hazard rate as implied by the text and figure.
5. The formula (Eq. 5.30) for wavelength distribution of radiant energy holds for a black body only—most bodies are not black. This is one of the main problems involved with infrared analysis; viz., emissivity is a function of wavelength and surface detail.

Section 6: A section on statistical methods is extremely difficult to write and the level on which to pitch the presentation is difficult to determine. The selection of the authors cannot be faulted in this respect regardless of the fact that each expert in the subject would probably have his own favorites to discuss and his own methods of discussing them. Generally speaking, the discussion follows the usual lines and is not likely to mislead engineers. Several items were not brought out that concern the controversial relationship of statistics to engineering. Some of these are:
1. Statistical significance is a technical term in the statistical literature and is explicitly defined in a particular way. There is not necessarily any relationship to engineering significance; in fact, one can (and often does) have one without the other.
2. Statistical confidence is likewise a technical term in the statistical literature and is explicitly defined in a particular way. There is no fixed relationship to engineering confidence; one often has the one without the other.
3. As the authors suggest, the population about which one is making statistical inferences is defined as the population from which the sample was truly a random one.
4. In testing the goodness of fit there is a severe problem. For a technique such as the Chi Square test, there are often so few data or groups that the power is very low; i.e., the data can be said to fit most any distribution. On the other hand, if there are many data or groups, the power of the test is too high and the hypothesis of having a particular distribution will probably be rejected even though for engineering purposes it is close enough. One does not really wish to know whether there are significant statistical differences between the observed data and the model. He wishes to know if these differences are of engineering importance. For example, one could have enough data to show that a distribution was not quite Normal, but the distribution might still be close enough to Normality for engineering purposes, especially between the $\pm 2\sigma$ limits.
5. Rarely, if ever, will a statistician explicitly address himself to the question for which the engineer wants an answer. Most often the statistician deals with a null hypothesis. That is, he says "Assume that the situation is in fact like our simple statistical model. What then are the odds that we would observe anything that deviates as far from the model as we have here?" But this is not the exact question the engineer is interested in and he goes on from the statistician's result at his own peril. He *will* have to go on from there but he should realize that he is doing it on his own engineering knowledge (assisted in small part by the statistical result) not as a logical extension of mathematics.
6. When a least-squares analysis is used, most often it should be weighted least-squares (the weight of a point is inversely proportional to the expected variance at that point). This is especially important when the data have been transformed to get a straight line. Not only will the engineer have to concern himself with the statistician's estimate of the variance but his own estimate about the kind of variation he would expect in the data. When the numbers cover several decades, this can be particularly important because the unweighted assumption of a constant arithmetic uncertainty is likely to be quite erroneous. More often there is a small numerical uncertainty plus a percentage-of-the-reading uncertainty. (The accuracies of many instruments are often given in this way for that reason.)

As stated in the beginning of the review, Sections 1 and 4 contain severe deficiencies and should not be used. Section 2 has a greatly misplaced emphasis. Sections 3, 5, and 6 will be helpful to engineers who are doing reliability physics.

R68-13548 ASQC 800

INDUSTRIAL QUALITY CONTROL, VOLUME 23, NUMBER 8.

Feb. 1967 p. 370–404. 18 refs. Selected articles

Six articles dealing with industrial quality control and reliability programs are presented. The flight test program for the C-141A cargo aircraft is reviewed, along with the role of reliability in decision making related to a proposal for the Voyager program. Various methods of sterilizing electronic parts for space flights are described, and raw product analysis is considered as a system approach to the problem of preventing degradation of design reliability during product manufacture. Differences are presented in predicted reliability figures obtained by methods of MIL-HDBK-217 and 217A, and a design review procedure is discussed that produces more than $23 for each dollar invested. M.W.R.

Review: The six papers in this issue of *Industrial Quality Control* were reprinted (some slightly abridged) from the Proceedings of the 1967 Annual Symposium on Reliability. They were covered, respectively, by R67-13316, R67-13195, R67-13250, R67-13201, R67-13246, and R67-13192.

R68-13562 ASQC 802; 844

Defense Dept., Washington, D. C.

RELIABILITY STRESS AND FAILURE RATE DATA FOR ELECTRONIC EQUIPMENT Military Standardization Handbook

8 Aug. 1962 337 p refs

(MIL-HDBK-217; N64-84585)

Procedures for implementing MIL-STD-756 on contracts and for improving prediction accuracy are covered in *Reliability Stress and Failure Rate Data for Electronic Equipment.* Reliability prediction techniques useful at various stages of a program are presented. All failure rate data presented are based on both laboratory tests and vendor test reports, and a section on K-factors is included. Some high reliability specifications are included; and the failure rates for parts covered by non-high reliability specifications are averages or a mean value of failure rates whereas the established reliability specification failure rates are guaranteed minimum values when the parts are used under their stated operating conditions. A table outlines the manner in which the handbook can be used to define the system, construct a reliability model, and make predictions. Reliability prediction based on stress factors and actual part populations; part failure rates; approximations for reliability calculations; and part, circuit, and system degradation are also considered. M.W.R.

Review: Contents of this handbook are mainly failure rate versus stress curves of electronic items, as the title notes, plus a moderate amount of material on reliability prediction equations. The latter is somewhat disconnected and incomplete. Conventional practices are reflected, and the type of presentation is of the leading-by-the-hand style. This document is a basic reference for reliability prediction, but the user should be sure to have the issue as dated above (MIL-HDBK-217A) for there are quite a few changes over the superseded issue (MIL-HDBK-217). Also, this volume cites several other sources of reliability prediction data in Section 1.4. Of these, the FARADA program which is now at the Naval Fleet Missile Systems Analysis and Evaluation Group (FMSAEG) at Corona, California has a working information program which expands in a meaningful way on the type of failure-rate information in MIL-HDBK-217A. The person seriously interested in reliability prediction will want to see beyond the rote reliability prediction procedures given in this handbook. There are many assumptions associated with these procedures; it is most important for practitioners to understand these assumptions and the gross

nature of this type of analysis so that they do not make fools of themselves. In a private communication a representative of the Naval Air Systems Command has indicated that work is in progress to improve MIL-HDBK-217A and that a superseding document, MIL-HDBK-217B, should be published late in 1968.

R68-13586 ASQC 800; 870
Society of Automotive Engineers, Inc., New York.
PRODUCT EFFECTIVENESS CONCEPTS IN DESIGN
Frank M. Gryna, Jr. (Bradley Univ.) Jan. 1966 7 p refs
Presented at the Automotive Eng. Congr., Detroit, 10–14 Jan. 1966
(SAE Paper-660089; N67-86595)

Product value and product effectiveness are defined, and a simple approach for design engineers to quantify the reliability and maintainability effectiveness parameters is presented. Responsibility for achieving product effectiveness is considered to rest with all of the line organizations in a company, including the design engineer and the people involved in manufacturing. The suggested approach is an availability index that specifies, predicts, and measures factors affecting availability; and the index used should suit the specific needs of the product. One possible index is average life divided by average repair time; and estimation of life and of repair time are discussed along with the use of data from previous designs. It is suggested that prior to the start of the design the engineer should set a numerical goal for his design in terms of a simple index that can later be compared with actual achievement. M.W.R.

Review: About half of this paper is an exhortation to designers and management to consider figures of merit such as reliability and availability and the other half is a very general outline of estimating life, reliability, etc. for a product. This paper is for those not familiar with the field, who need to be convinced that high reliability is worthwhile, and who do not yet know that reliability and maintainability can be quantitatively treated during the design of complex mechanical products.

R68-13594 ASQC 800
SOME ASPECTS OF RELIABILITY IN REACTOR INSTRUMENT SYSTEMS.
T. L. McLean
Nuclear Safety, vol. 8, Summer 1967 p. 356–359. 22 refs.

The field of reliability engineering grew as a necessary part of the development of the complex electronic systems used in military and aerospace installations and was expanded as a useful tool in operations research and system engineering. An examination of the sensitivity of reactor protection systems to various types of failures is one application of this technology. Other uses of reliability engineering include the comparison of systems and the development of higher reliability systems. Because component failure is not the leading cause of reactor accidents, reliability cannot become the singular champion of nuclear safety. There are, however, useful applications of reliability technology to the improvement of the safety, operability, and economics of nuclear power stations. Author

Review: This is a review of some of the accomplishments in reliability technology as applied to electronic systems in military and aerospace installations. The discussion is keyed to 22 references. Possibilities for application of this technology to reactor instrument systems are explored. While the paper is apparently written for designers of such systems, it has value for anyone concerned with the design of production of high-reliability equipment. A major conclusion is that good design and plant management, which are essential to high reliability, cannot be achieved through probabilistic methodology. An important element is attention to detail or, in the author's words, "tender, loving care on the part of the workmen."

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13551 ASQC 810; 300
Defense Dept., Washington, D. C.
PROCEEDINGS DEFENSE CONFERENCE ON QUALITY AND RELIABILITY MANAGEMENT, VOLUME I AND VOLUME II
Aug. 1966 312 p refs Conf. held in Annapolis, Md. 2–4 Aug. 1966
(AD-648315; AD-648316; N67-39646; N67-40068) CFSTI: HC $3.00/MF $0.65

Panel reports of a conference dealing with quality control and reliability management are presented in two volumes; the first includes summaries of topics discussed and recommendations for meeting the problems encountered, while the second goes into details of the panel proceedings. Panels deal with quality control and management concepts and aspects of the development and production phases; quality assurance in storage and maintenance operations; reliability and maintainability assessment, personnel and training, and metrology and calibration in quality and reliability operations. M.W.R.

Review: This is an unusual conference because part of the audience has had the opportunity to react previously to the material. Each of the nine panels had pre-conferences and thus there was time for panel exploration of problems before this conference. Perhaps this approach to conferences has potential applicability elsewhere. This is one of a continuing series of such conferences in the various DoD problem areas, although it was the first one on reliability and quality. Essentially all of the topics in the "...abilities" are touched on at least once in these conference proceedings, although the "big picture" gets more attention than do the "details." Generally, the recommendations are for "more and better" of the approaches which are being attempted. No "breakthrough" recommendation is readily apparent. To some degree there is self criticism here. Volume I summarizes nicely the findings and recommendations of each of the nine panels. It is reasonably well suited for complete reading; it would have been better for this purpose had it been more concise. Volume II has the details of each panel and thus best serves the purpose of a reference for those interested in more detail. Although DoD sponsored this conference, there was participation by other government agencies. The conference purposes would have been better served through some non-government participation, including representation from the "...abilities" as well as from design and manufacturing.

R68-13558 ASQC 815; 844
NEW THINKING ON PRECISION FILM RESISTOR RELIABILITY.
O. A. Keser (Speer Carbon Company, Jeffers Div., Dubois, Pa.).
Evaluation Engineering, vol. 6, Sep./Oct. 1967, p. 22–24.

Factors involved in precision film resistor reliability are discussed, with implications to other resistor types and a variety of

electronic components. Present film resistor specifications are not considered to offer sufficient incentive for built-in component reliability; and emphasis is on testing against arbitrary criteria with limited funds devoted to reliability achievement programs. Weaknesses of MIL-R-55182 are noted, along with the problems involved in screening tests and inadequate testing methods. Close scrutiny of uniformity during and after manufacturing is considered useful in reliability assessment of resistors; and steps are offered for assessing design, material, and process control factors. Efforts are needed in product engineering, application engineering, and environmental test engineering to achieve greater precision film resistor reliability. M.W.R.

Review: This paper deals largely with the engineering considerations of resistor reliability and the specification thereof rather than statistical tests. The confidence level is mentioned as the factor which governs the amount of testing; it is, of course, the reliability in combination with the confidence level that govern the amount of testing. In this connection, although not mentioned by the author, it is worthwhile noting that perfection at zero confidence is not worth very much and that where the probability of defectives is extremely small, the probability of a wrong decision (the complement of confidence) should be of the same order of magnitude for the results to have practical meaning. For example, a maximum of 10^{-6} failures at 60% confidence is lopsided in these terms. The limitations of specifications are well pointed out, as are some of the weaknesses in testing to meet those specifications. The idea of a combined overall tolerance is an appealing one. But if we had it, it is reasonably certain that many people would want to break it down again, especially when things went wrong. The latter problem is at the root of many of the discussions about reliability specifications and the proving thereof. When everything is going well one wishes to have as little detail as possible, but when things go wrong the customer wants to be able to assist the manufacturer in finding the source of difficulty. In fact, the manufacturer may need such assistance if the customer is to get the quality he is demanding and then the details in the specification are helpful. The suggestions at the end of the article for modifying specifications and ways of specifying resistors are good although their implementation may create other problems. It was apparently not the purpose of this article to explore everything in depth, and the article does a good job of raising questions that need to be raised. The author in a private communication has indicated that he considers the sense of the section on screening tests to be a key element in the paper. He goes on to say: "The effectiveness of screening tests is their ability to assess uniformity. Present specifications are not couched in terms which permit a suitable determination of uniformity using established statistical methods, such as control charts."

R68-13563 ASQC 813; 830
American Society for Metals, Cleveland, Ohio.
IMPLEMENTATION OF HIGH RELIABILITY OBJECTIVES OF SURVEYOR PRESSURE VESSELS
Frederick W. Anderson (Hughes Aircraft Co.) Nov. 1966 30 p Presented at Natl. Metal Congr., Chicago, Ill., 31 Oct.–3 Nov. 1966.
(TR-C6-2.1)

The methodology used to attain high reliability objectives is presented for over 350 6Al–4V titanium pressure vessels involving seven different configurations used on the Surveyor spacecraft. Drawings of specifications, no matter how detailed, do not by themselves guarantee a delivered successful pressure vessel. A concerted effort in project engineering management and technical support in the areas of metallurgy, process control, manufacturing and testing are necessary. The major problem area in pressure vessel manufacturing is welding, which can be minimized by specifying the use of fully automatic welding equipment and by carefully preparing a weld development test program. Proper attention should be given to the review of detailed procedures with active participation by the cognizant customer engineer to insure that adequate tests and controls are performed to provide an overall check on manufacturing processes. Author

Review: The reliability philosophy in this paper is very good: it shows how engineering knowledge is used to give engineering assurance of high reliability; it demonstrates the necessity for attention to detail in all phases of the product cycle. In any management scheme for high reliability it is important to remember that no matter how good the paper organization, if the people involved do not carry out their tasks conscientiously and aggressively, success is unlikely. Some minor criticisms of the paper are: 1. It is easy to infer from some of the statements that the statistical and engineering approaches to reliability are mutually exclusive. This certainly need not be so; they complement each other very well. 2. To require less than 0.002% defective at 80% confidence seems a poor choice of percentages. It appears to be too far in direction of "Perfection at zero confidence." It is more appropriate to have chance-of-finding-a-defective and the chance-of-being-wrong much closer together. 3. Some of the test results imply that the strength measurements have a relative accuracy of 10^{-4} which is not ordinarily available. That these criticisms are minor, helps to point up the soundness of the approach to reliability given in the text.

R68-13588 ASQC 810; 844
McDonnell Aircraft Corp., St. Louis, Mo.
ASSURED GEMINI RADAR RELIABILITY
Joe H. Scrivner Nov. 1965 12 p ref Presented at NEREM 65, Boston, Nov. 1965
(N67-86593)

Reliability problems related to the Gemini radar system are reviewed in terms of both design and actual operations. It is noted that excess derating can be detrimental, that unexplainable failures should be regarded suspiciously, and that test equipment must be foolproof. Humidity, vibration, and vacuum aspects are considered; and mention is made of the Gemini 5 flight analysis and the reentry and abort test of Gemini rendezvous radar. M.W.R.

Review: This paper is one presented at a meeting and is quite suitable for that purpose. It is essentially a collection of interesting case histories showing some reliability problems. The orientation is very practical and reading this can help give meaning to the admonitions that engineers often hear but equally as often ignore. It is short and interesting to read, both of which are distinct assets.

R68-13592 ASQC 810; 813; 864
National Aeronautics and Space Administration, Washington, D. C.
FAILURE REPORTING AND MANAGEMENT TECHNIQUES IN THE SURVEYOR PROGRAM
D. S. Liberman, F. A. Paul (Jet Propulsion Lab.), and E. F. Grant (Hughes Aircraft Co.) 1967 43 p
(NASA-SP-6504; N67-90166) CFSTI: $3.00

Failure reporting and corrective action activity for the Surveyor spacecraft and operational support equipment are discussed. Details of the trouble failure reporting system (TFR) and the NASA management techniques built into it are included; and underlying philosophy, closure criteria, and system management are discussed. Function and administration of a review system for the basic TFR are noted, along with the NASA headquarters participation in its implementation. Failure reporting for Surveyor mission operations is discussed; and a bulletin on Surveyor trouble and failure reporting

includes diagnosis, correction, and closeout. The trouble and failure report is shown, as are typical pages from a weekly printout giving status of open mission critical TFR's. M.W.R.

Review: This is a good, straightforward description of a failure reporting and corrective action system. Many of the techniques are not new or unique, nor are they claimed to be so. Since there is generally a lack of good *detailed* descriptions of such systems in the literature, the report makes a worthy contribution. It is quite complete, with much detail given, including many examples of forms and procedures. The many people and organizations involved in a program such as Surveyor make it extremely difficult to achieve and maintain a workable system. A reasonably good job of planning and organizing appears to have been done, while at the same time making available a degree of flexibility. As its Foreword indicates, this is a report of experience and practice. It will be valuable for future reference on similar programs. An essential to the success of any such program, as pointed out in the Concluding Remarks, is continuous, whole-hearted management attention by all concerned.

R68-13596 ASQC 810; 844
CRITERIA FOR ASSESSING THE RELIABILITY OF TOTAL COMPUTER SYSTEMS.
William E. Marshall (Control Data Corporation, Reliability Department, Product Analysis Section, Minneapolis, Minn.).
In: WESCON/66; Western Electronic Show and Convention, Los Angeles, Calif., August 23–26, 1966. Technical Papers. Session 21—High-Availability Computer Systems. Los Angeles, Western Electronic Manufacturers Association, 1966. 7 p. 2 refs.

Joint cooperation between producer and user are considered basic to easier and more reliable assessment of digital computer reliability; and industry-wide ground rules for reliability assessment are recommended. The need for reliability assessment, problems related to this assessment, and a requirements definition are presented. Some assessment ground rules are included; and failure identification, classification, and data recording are discussed. Mean time between failure (MTBF) and general reliability categories that can be used to determine figures of merit are listed. M.W.R.

Review: This paper is written for reliability program managers, and lists management criteria which must be considered when performing a reliability assessment. While some parts of the discussion pertain to features which are unique to digital computer systems, most of the material has much wider applicability. In particular, the checklist which appears in the appendix should be of general utility to reliability program managers. Other noteworthy features are the need for producer-user communication and the importance of adequate definition of what the producer and user expect from each other. The paper contains an example of the latter need in its reference to a document which lists definitions of reliability terms. The term "inherent reliability" is said to have seven definitions. This term is a poor one and is often used in the reliability literature without specific definition by the user, so that the reader is often left to his own interpretation as to what the author means. In summary, this paper is short, clearly written, and contains a number of good management ideas, apparently based on a wealth of practical experience.

R68-13597 ASQC 815
MONITORING RELIABILITY REQUIREMENTS BY TOTAL SYSTEM SPECIFICATION AND DESIGN.
Reynold Thomas, Jr. (Defense Communications Agency, Washington, D. C.).
In: WESCON/66; Western Electronic Show and Convention, Los Angeles, Calif., August 23–26, 1966. Technical Paper. Session 21 High-Availability Computer Systems. Los Angeles, Western Electronic Manufacturers Association, 1966. 5 p.

An overview is presented of the approach used in the procurement of switches for the AUTODIN program, which provides military establishments and government agencies with a single worldwide automatically switched network for command control, logistics, and administration communications. Emphasis is placed on the monitoring of reliability requirements by total system specification and design; as well as the use of a concept of systems effectiveness for AUTODIN. The concept used is based on four performance parameters that represent long-term operational performance and a technique of partitioning a complex system into units and subsystems which eventually increased standardization of proposals and simplified the evaluation process. M.W.R.

Review: A very general description is given of the way in which the effectiveness concept can be used as a tool in dealing with system reliability problems. While specific reference is made to a particular highly reliable message switch, the points made in the paper are applicable to a wide range of components and systems. The approach described can increase the user's visibility over the system, enabling him to assess the impacts on it of changes in design, hardware, and procedures. As the author has pointed out, it is useful in the specification stage and throughout the proposal, evaluation, procurement monitoring, acceptance, and into the system management phases of the life of the system. While the paper is a good general description, its value to the user would have been enhanced by the inclusion of a case history in some detail.

R68-13601 ASQC 815; 614
SETTING RELIABILITY INCENTIVES USING LINEAR PROGRAMMING.
R. Maloney (Sperry Rand Corp., Sperry Gyroscope Co., Information and Communications Div., Great Neck, N. Y.).
(Institute of Electrical and Electronics Engineers, International Convention, New York, N. Y., Mar. 21–25, 1966, Paper.) IEEE International Convention Record, vol. 14, pt. 9, 1966, p. 119–124. (A66-24669)

Discussion of an alternative method of determining an incentive fee schedule for government contracts based on linear programming techniques. It is noted that the present method of determining an incentive fee schedule for reliability reduces much of the subjective elements generally present in determining incentive schedules, and requires only four subjective quantities. With these data, a fee-vs-failure schedule can be determined very easily using linear programming techniques. The technique has only been used for fixed time tests. It is pointed out that, since many reliability tests are performed sequentially, it may be useful to try and apply the technique to sequential tests. IAA

Review: A brief and easily-read description is given of the application of linear programming to establishing reliability incentives. The incentives are considered to be based only on performance, that is, on the number of failures observed in testing the item under specified conditions. The technique recognizes that the incentive fee is a random variable and indicates how one might relate the fees to the number of observed failures subject to certain conditions on the relative values of those fees. This paper should be of value to those concerned with the management of hardware contracts.

R68-13604 ASQC 810
A HISTORY OF SELECTED RELIABILITY AND MAINTAINABILITY COMMITTEES AND INTERESTED GOVERNMENT AGENCIES.
John de S. Coutinho (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).

American Institute of Aeronautics and Astronautics, Annual Meeting, 3rd, Boston, Mass., Nov. 29–Dec. 2, 1966. 24 p 39 refs (AIAA Paper-66-856; A67-12259) Members, $0.75; Nonmembers, $1.50.

The role of some selected committees and interested Government agencies is examined in developing a new engineering discipline in the area of reliability and maintainability, and in disseminating this information and know-how throughout the aerospace industry. The specific contributions of some representative committees and Government agencies are discussed, within the framework of their product and functional orientation.

Author (IAA)

Review: This is a quite worthwhile description of the topic indicated in the title. While the term "selected" relieves the author of any responsibility for the completeness of his listing, he does not seem to have left out any committee or Government agency that has made an important contribution to these disciplines. Those statements which are expressions of the author's opinion do not appear to be particularly controversial—some of them may, in the opinion of some, be overly generous. This will be a good paper for reliability and maintainability managers to read, and perhaps to file for future reference, since it contains some potentially useful information. Thirty-nine references are cited.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13552 ASQC 824
Carnegie Inst. of Tech., Pittsburgh, Pa. Management Sciences Research Group.
STATISTICAL ESTIMATION IN A PROBLEM OF SYSTEM RELIABILITY
D. P. Gaver and M. Mazumdar (Westinghouse Elec. Corp., Pittsburgh, Pa.) Feb. 1967 40 p refs Prepared in cooperation with Westinghouse Electric Corp.
(Contract Nonr-760(24))
(RR-89; AD-648085; N67-39643) CFSTI: HC$3.00/MF$0.65

The statistical estimation of the reliability of a simple system, subject to exponential failures and subsequent repairs, is considered. Observations are assumed taken at isolated instants (snapshots), and for also continuous periods of time (patches); the information is combined by maximum likelihood. Procedures for improving small-sample properties of estimates are studied by Monte Carlo sampling experiments. The robustness of the estimates is similarly considered.

TAB

Review: The first third of this paper is a presentation of maximum likelihood estimation for a two-stage Markov model in which the process is generated by exponential distributions of up- and down-times. It is clearly presented, competent mathematical work, adequately keyed to references to related literature. The last two-thirds of the paper consist of an investigation by experimental sampling aimed at determining the adequacy of the maximum likelihood estimators and also at evaluating empirical adjustments which may be made to improve their performance. The robustness of the estimates, i.e., their behavior when some distribution other than the exponential governs the observations, is also investigated. While the sampling experiments do not yield absolutely conclusive results, they do give useful indications regarding the behavior of the estimates. The paper will thus be of value to statisticians who are designing or helping to design sampling plans for reliability analysis purposes.

R68-13553 ASQC 824; 872
RAND Corp., Santa Monica, Calif.
A TEST FOR THE INDEPENDENCE OF TWO RENEWAL PROCESSES
Sidney C. Port and Charles Stone Sep. 1966 17 p refs
(Contract AF 49(638)-1700; Proj. RAND)
(RM-5124-PR; AD-640269; N67-15358) CFSTI: HC $3.00/MF $0.65

This study develops a large sample test for the independence of two renewal processes. Such a test should be useful in connection with certain neurophysiological experiments and in reliability and maintenance procedures for stochastically failing equipment.

Author (TAB)

Review: This is a highly technical paper, the basic result being a "central limit theorem" (i.e., convergence in distribution to Normality) for certain random variables obtained from two independent renewal processes. While the result has potential applicability to problems in reliability and maintainability, the paper will be of interest only to the theorist. Unfortunately, both the random variables and parameters of the limiting Normal distribution involve constants (certain moments) which may not be known. The long proof of the theorems is quite complex and not all of the detailed mathematics was checked.

R68-13554 ASQC 824
Boeing Scientific Research Labs., Seattle, Wash. Mathematical Research Lab.
A MULTIVARIATE NOTION OF ASSOCIATION, WITH A RELIABILITY APPLICATION
J. D. Esary, Frank Proschan, and D. W. Walkup Oct. 1966 26 p refs *Its* Math. Note No. 484
(D1-82-0567; AD-644094; N67-19226) CFSTI: HC $3.00/MF $0.65

Random variables T1,T2,...,Tn are, in this paper, associated if each pair of non-decreasing functions F(T1,T2,...,Tn), G(T1,T2,...,Tn) have a non-negative covariance. Association holds in cases ranging from T1,T2,...,Tn independent to T1,T2,...,Tn jointly restricted to a non-decreasing curve. Association is preserved under the standard multivariate operations of extracting subsets and pooling independent sets; and under the special operation of forming sets of non-decreasing functions. Suitable choices of F,G lead to various inequalities for associated random variables. The properties of association are studied in the simple, but representative, case that T1,T2,...,Tn are finitely discrete. The notion of association is useful in extending the domain of validity of the minimal cut lower bound for the reliability of a coherent system, notably (here) to the case of repairable components with exponential times to failure and exponential times to repair.

Author (TAB)

Review: This report presents an interesting definition of the notion of several random variables being *associated.* The definition is a somewhat natural extension of the idea that two random variables are associated if their covariance is non-negative. Several properties of the definition are obtained, especially for discrete and binary random variables. The idea of association is then applied to obtain lower bounds for certain reliabilities. The overall quality of the report is excellent and we can hope that further work in this area will be forthcoming.

R68-13559 ASQC 822; 424

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

A GENERALIZED BIVARIATE EXPONENTIAL DISTRIBUTION

Albert W. Marshall and Ingram Olkin (Stanford Univ.) Oct. 1966 24 p refs

(D1-82-0572; AD-644120; N67-22393) CFSTI: HC $3.00/MF $0.65

In a previous paper ("A Multivariate Exponential Distribution," AD-634335) the authors have derived a multivariate exponential distribution from points of view designed to indicate the applicability of the distribution. Two of these derivations are based on "shock models" and one is based on the requirement that residual life is independent of age. The practical importance of the univariate exponential distribution is partially due to the fact that it governs waiting times in a Poisson process. In this paper, the distribution of joint waiting times in a bivariate Poisson process is investigated. There are several ways to define "joint waiting time." Some of these lead to the bivariate exponential distribution previously obtained by the authors, but others lead to a generalization of it. This generalized bivariate exponential distribution is also derived from shock models. The moment generating function and other properties of the distribution are investigated. Author (TAB)

Review: This report presents an interesting extension of some earlier work of the authors (see R67-13096) on certain bivariate exponential distributions. (Reliability applications of this distribution were treated in the report covered by R67-13301.) Here the motivation is the fact that the univariate exponential distribution governs the waiting times in a Poisson process. Thus bivariate Poisson processes and various ways of defining "waiting times" in such processes are explored. The exposition is quite clear and the report can be recommended to those interested in new multivariate distributions which may prove useful in applications.

R68-13564 ASQC 821; 838

FATIGUE LIFE AND RELIABILITY OF A REDUNDANT STRUCTURE.

R. A. Heller and A. S. Heller (Columbia University, Institute for the Study of Fatigue and Reliability, New York, N. Y.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 4th, Los Angeles, Calif., July 28–30, 1965. Volume 4—Practical Techniques and Application. Edited by John de S. Coutinho. Washington, Spartan Books, Inc., 1965, p. 881–896. 15 refs.

(Contract Nonr-266(91))

(A66-10119)

Brief discussion of life calculations for a fail-safe redundant structure. A new "incomplete damage" function predicting failure when the reduced strength of the material falls below the applied stress was developed. The expression utilizes linear-damage accumulation but contains terms to validate it for both variable and constant-amplitude load applications. It is shown that the "complete (Miner) damage" rule cannot be used with such a failure criterion. Based on a mathematical model derived from probabilistic considerations, fatigue and ultimate load lives were obtained for structures subjected to variable and constant loads and made of a material having statistically distributed or constant strength. The use of a nonstatistical strength produces nonconservative results for severe load distributions and more conservative ones for constant loads. Life estimates based on the Miner rule exhibit similar tendencies. The reliability of the structure and of its weakest member were calculated and fail-safe lives were obtained for structures with members having statistically distributed strength. Such estimates cannot be obtained from the Miner rule or from a nonstatistical strength assumption. The use of an exponential strength distribution limits the applicability of the calculations, but the trend of the results is expected to remain unchanged with the assumption of other more realistic distribution functions for which, however, the analysis is much more involved. It is pointed out that experiments currently in progress on a ten-member structure, although incomplete, tend to substantiate the foregoing findings. IAA

Review: This paper is a virtual duplicate of its Reference 2: Technical Report No. 17, Institute for the Study of Fatigue and Reliability, Columbia University, March, 1965. This paper is stated to be an extension of that report, but in a later Note, a reference implies that the previous two are the same. Those who refer to this rather than the earlier document are warned that there is an extensive errata which should be consulted. Well over half of the equations contain type-setting errors—unfortunately the authors were not sent galley proofs.

R68-13565 ASQC 824; 838

ESTIMATES FOR BEST PLACEMENT OF VOTERS IN A TRIPLICATED LOGIC NETWORK.

Karyl J. Gurzi (General Motors Corp., AC Electronics Div., El Segundo, Calif.).

IEEE Transactions on Electronic Computers, vol. EC-14, Oct. 1965, p. 711–717. 4 refs.

The reliability of a network of elements may be improved by triplicating the network and determining the output using majority voting logic. The reliability of the triplicated network depends on how the network is subdivided for voting purposes and the type of majority voting logic used. The optimum arrangement of elements and voters is established for the single voter scheme, and an estimate of the optimum arrangement is derived for the three voter scheme. Upper and lower bounds on possible improvements through triplication are determined, and a comparison is made of the single voter and three voter schemes. All results are presented in graphical form. Author

Review: This paper is the analysis of several mathematical models for triplicated logic networks. In addition to the assumptions made explicitly by the author (viz., constant hazard rates for the elements, statistically independent failures, and permanent failures), the behavior of the elements is presumed to be either good or bad without qualification. As pointed out in [1], the latter assumption is not necessarily a realistic one. Other papers in the past have also mentioned this. The analysis of the model appears to be competent although not all of the mathematics was checked. The graph showing the results should be helpful to anyone involved in a design problem. (It is not good practice to equate, as the author does, "being random" with "having a constant hazard rate"; there are distributions of random variables other than those which have constant hazard rates.)

Reference: [1] Paul H. Giroux, "Estimates for best placement of voters in a triplicated logic network" (Letter to the Editor), *IEEE Transactions on Electronic Computers,* vol. EC-15, Jun 66, p. 382.

R68-13566 ASQC 821; 844

DIMENSIONLESS PARAMETER RELIABILITY ANALYSIS AND APPLICATION TO MECHANICAL CREEP.

R. Simon (Battelle Memorial Institute, Columbus Labs., Columbus, Ohio).

(American Society of Mechanical Engineers, Winter Annual Meeting, Chicago, Ill., Nov. 7–11, 1965, Paper 65-WA/MET-6). ASME, Transactions, Series D—Journal of Basic Engineering, vol. 88, Mar. 1966, p. 87–92. 15 refs.

(A66-15689; A66-24540)

A formal procedure is outlined for establishing a priori functional relationships between the probability-of-success measure of reliability and dimensionless parameter combinations of the pertinent system variables. The latter include the criteria for failure, the expected load and environmental conditions, the statistical distributions in values of the material properties, and the explicit and implicit times. This procedure is illustrated by application to the case of structural element creep assuming a bimodal failure criterion, either exceeding a given critical strain level or rupture. The implications of this analysis in regard to indicating the directions of future research in materials science pertinent to mechanical reliability are briefly discussed. Author (IAA)

Review: This is a highly theoretical paper since it analyzes a system model which is derived from many somewhat arbitrary assumptions and there is at present no method by which it can be compared with experiment. In addition to being theoretical, the paper is somewhat speculative, but not unduly so. If the speculative nature of the paper is not appreciated, it would be very easy to denigrate it. The paper does show, by means of the hypothetical example, how the properties of materials may be used to give a more accurate expression for the probability of failure of mechanical systems. The analysis of the model proceeds reasonably, although not all the mathematics was checked. There is one error in the paper although it does not affect the development, viz., the formula for MTBF in the paper is in reality the reciprocal of the hazard rate whereas the MTBF, or more accurately the MTTF (for no scheduled maintenance), is properly defined as

$$\mathrm{MTTF} = \int_0^\infty t(-dR/dt)dt = \int_0^\infty R\,dt.$$

The explanation, for the constant hazard rate, which follows the formula is then backwards: when the *hazard rate* is constant its reciprocal is the MTTF. The discussion of failure modes, their independence, and the proper way of combining the probabilities of occurrence are not handled well. In this situation there are two failure modes. The first is a catastrophic rupture and the second is reaching a critical strain. Given that the first is mentioned, the second must imply the additional phrase, "...given that rupture does not occur;" otherwise the first failure mode is merely a special case of the second. When the definitions of the failure modes are phrased completely, it is easy to see that they are mutually exclusive. They cannot be statistically independent if they are mutually exclusive; so the discussion which gives other criteria for independence is irrelevant and the part that assumes, for the purposes of the example, that they are statistically independent is wrong. The general question of when failure events are mutually exclusive and when they are statistically independent has had little explicit discussion in the literature since most of the assumptions that are made are not analyzed at length. A problem arises with Eq. 7 wherein the reliability is the product of the ordinary exponential in time and some function of the parameters: $R = [\exp(-t/t_c)]f(\Pi_2, \Pi_3, \ldots \Pi_n)$. If $R(t=0) = 1$, according to custom, then $f \equiv 1$ regardless of anything else and so its inclusion is irrelevant. Perhaps what could be said instead is that the critical time (t_c) is a function of these parameters. The emphasis on dimensionless parameters is overdone. Naturally for any equation to be numerically meaningful the physical units must balance out. And there can be no net physical units in the argument of a non-algebraic function (such as sine or exponential) unless it is effectively cancelled somewhere else. Thus any of the parameters that are used can be rendered dimensionless eventually even if one has to strain at it. But there is a large portion of engineering which is based on the use of parameters with distinct dimensions, such as spring constant and resistance; there is little need to eliminate that use from consideration. In new work, however, the use of dimensionless parameters can stimulate the search for new and appropriate variables.

R68-13567 ASQC 821; 838; 872

DETERMINATION OF MEAN-TIME-BETWEEN-FAILURES OF DUPLICATED DEVICES WITH CONTROL AND AUTOMATIC SWITCHING APPARATUS.

A. L. Garkavi and V. B. Gogolevskii

(Avtomatika i Telemekhanika, vol. 26, May 1965, p. 906–914.) *Automation and Remote Control,* vol. 26, Dec. 1965, p. 903–911. Translation.

(A65-28451; A66-17388)

Determination of the average time of failure-free operation of a system consisting of two devices duplicating each other. The regime of the standby device is taken to be arbitrary. It is assumed that the system is equipped with a monitoring and switching apparatus. The possibility of restoring malfunctioning devices is provided for. Author (IAA)

Review: This paper calculates the mean time between failures for a system which operates with any of several maintenance conditions. The times-to-failure of the components of the system are presumed to have a constant hazard rate. The down time has two possibilities: it is either a constant or it has a constant hazard rate. For redundant systems the mean time between failures is not necessarily the best figure of merit. It was calculated here because it was possible to do so; the general formula for probability of failure could not be obtained. For mission times short compared to the mean life of a component the failure rate or hazard rate is often a much better figure of merit for a system. The mathematics was not entirely checked but it appears to be competent. Several examples and special cases are worked out. The general formulas are tedious to evaluate.

R68-13568 ASQC 821

COMPUTING THE RELIABILITY OF LOGICAL COMPONENTS AND SINGLE-CYCLE CONTROL SYSTEMS.

S. M. Domanitskii

(Avtomatika i Telemekhanika, vol. 26, May 1965, p. 898–905.) *Automation and Remote Control,* vol. 26, Dec. 1965, p. 896–902. Translation.

(A65-28450; A66-17387)

Description of a method of calculating the reliability of logical elements and systems with given probabilities of failure of individual parts of elements and given probabilities of the occurrence of various sets of logical variables at the input of an element or system. The use of this method is illustrated in the case of the widely known transistorized NOR circuits. This method can also be used for reliability calculations involving any other logical NOR elements. Author (IAA)

Review: The author is attacking a very interesting problem and one to which not much attention has been given in the literature. Unfortunately the paper contains errors in the mathematics/logic; so the results are not always accurate. If a process which is Poisson is partitioned, at least one of the resulting subprocesses cannot be Poisson. A similar statement holds true for statistical independence: if a set of events is partitioned, there must be statistical dependence among some of the subsets. The author has made assumptions which directly contradict these two theorems. His analysis will be more complicated should he take them into account.

R68-13570 ASQC 821; 844

ADDITION OF FATIGUE LIVES ON THE BASIS OF EQUAL PROBABILITY OF EQUAL DAMAGE.

R. D. Vagapov

(Zavodskaia Laboratoriia, vol. 31, June 1965, p. 725–730.) *Industrial Laboratory,* vol. 31, Nov. 1965, p. 890–895. 7 refs. Translation.

(A66-14400)

A probability method is suggested for assessing the fatigue strength when the stress range varies with time. It is shown that by the suggested method it is possible to separate functional relations of the accumulation and addition of damage from the random values. The paper also deals with the statistical relationships of addition. It gives an example of a simultaneous functional and statistical analysis of the discussed regularities of fatigue by dividing the process of cyclic loading into two characteristic stages. Author (IAA)

Review: This paper is very difficult to read and interpret. How much of the difficulty is due to the degradation in translation and how much of it is due to the ineptness of the original author is not known. The author appears to be making a valid point; viz., in a linear cumulative damage theory the probability curves should be taken into account since one may be using up considerably more or less than the average fraction of the life for a given number of cycles. Apparently the author then considers treating the fatigue damage in two stages which are separated by the appearance of the first crack. It will be difficult to get much from the paper because of the problems mentioned above, but it nevertheless may be of some interest to theorists who are willing to decipher it.

R68-13571 ASQC 821
ANALYSIS OF RELIABILITY OF RESTORABLE SYSTEMS.
E. S. Kochetkov
(Avtomatika i Telemekhanika, vol. 26, May 1965, p. 891–897.)
Automation and Remote Control, vol. 26, Dec. 1965, p. 889–895. Translation.
(A65-28449; A66-17386)

Determination of a reliability function for a restorable system with arbitrary laws of distribution of the time of failure-free operation of the system, the failure-detection time, and the restoration time. Three different methods of failure detection are considered. Author (IAA)

Review: This is a theoretical paper. The results are given in the form of equations, some of which are not tractable. Not all of the mathematics was checked but it appears to be of high quality. The paper can be of use to engineers who are sufficiently acquainted with probability theory and have sufficient access to numerical computation procedures so that they can handle the equations. The examples assume constant hazard rates for each of the three times (operating, failed and undetected, failed and being repaired).

R68-13573 ASQC 821; 872
TIMING OF CHECK OUT BEFORE A CRITICAL EVENT.
A. J. Truelove (C-E-I-R Inc., Beverly Hills, Calif.).
Operations Research, vol. 13, Nov.–Dec. 1965, p. 1036–1044.
(Contract NASr-21(08))

Approximate solutions were derived for repair times of a system of constant failure rate by both exponential and log normal distributions. The example used considers operation on demand in which the only criterion is that the system operates at a specified time in the future, with only one checkout and one repair are permitted. For exponentially-distributed failure times and log-normally distributed repair times, graphs are presented for the optimum checkout timing when all parameters are known. M.W.R.

Review: This brief note analyzes an interesting situation and presents the results in the form of an intractable equation and graphs resulting from a numerical analysis thereof. Not all the mathematics was checked, but it appears to be competent (there is a misprint following Eq. 3 wherein $\lambda t << 1$, rather than $\lambda << 1$). The results would be expected to be rather sensitive to the repair time distribution since if there were no repair the problem is trivial. The second derivation of the same equation is worthwhile and helps to give an engineering feeling for the results. Except for the addition of an introduction and the deletion of a comment on an approximation, this paper appears identical to one put out by this author and the RAND Corporation in 1964 [1].

Reference: [1] Alan J. Truelove, "Timing of checkout before a critical event," P-3014, The RAND Corporation, Nov 64 (AD-608 994; N65-18523)

R68-13575 ASQC 821; 838
THE RELIABILITY OF ELECTRONIC SYSTEMS.
J. C. Cluley (Birmingham, University, Dept. of Electronic and Electrical Engineering, Birmingham, England).
(Symposium on Engineering for Reliability in the Design of Semiconductor Equipment, Hatfield College of Technology, Hatfield, Herts., England, May 13, 14, 1965, Paper.) Radio and Electronic Engineer, vol. 31, Feb. 1966, p. 110–116. 9 refs. Research Supported by the Institution of Electrical Engineers and the Institution of Electronic and Radio Engineers.
(A66-15950; A66-23792)

Starting from the agreed definition of reliability the use of probability theory enables the design engineer to predict the reliability of a complex system as a function of the reliability of its component parts. The characteristics of series and parallel grouping are given, together with some applications of hammock networks. The exponential survival law is derived, and the conditions under which it may be applied are discussed. The use of redundancy to improve reliability is introduced, and examples are given of the effect of various schemes upon the reliability of a small electronic system, with and without maintenance. Some possible forms of passive redundancy are described, including block redundancy with majority voting, and quadded logic. Author (IAA)

Review: This paper is suitable for an introduction to the *calculation* of electronic system reliability wherein one is not interested in the details but only in getting a feeling for the kinds of things that are done. The details are not sufficiently accurate or clear to be used for calculations. Some of the restrictions are given only appreciably after the original formulas are proposed. The discussion of the Poisson series is incorrect; the series contains an infinite number of terms and sums to unity only under that condition. The requirement for statistical independence is implicit in most cases and is mentioned only part way through the paper. Unfortunately only the term independence is used and a physical cause and effect is implied by the discussion. While this is necessary for statistical independence, it is not sufficient. This discussion omits virtually entirely the engineering considerations for long life of the actual hardware. It is concerned largely with the calculation of the reliability, a limitation not apparent in the title. This kind of treatment has given rise to the complaints about much of the literature on electronic system reliability; i.e., it is concerned only with statistics and not with engineering.

R68-13577 ASQC 824; 512; 612
A MONTE CARLO TECHNIQUE FOR OBTAINING SYSTEM RELIABILITY CONFIDENCE LIMITS FROM COMPONENT TEST DATA.
Louis L. Levy (USAF, Systems Command, Electronic Systems Div., Bedford, Mass.) and Albert H. Moore (USAF, Air University, Institute of Technology, Wright-Patterson AFB, Ohio)
IEEE Transactions on Reliability, vol. R-16, Sept. 1967, p. 69–72. 14 refs.
(A67-37314)

A digital computer technique is developed, using a Monte Carlo simulation based on common probability models, with which component test data may be translated into approximate system reliability limits at any confidence level. The probability distributions from which the component failures are assumed to come are the exponential, Weibull (shape parameter K known), gamma (shape parameter α known), normal, and lognormal. The components can be arranged in any system configuration—series, parallel, or both. Since reliability prediction is meaningful only when expressed with an associated confidence level, this method provides a valuable and economical tool for the reliability analyst. Author (IAA)

Review: This is apparently a summary of the first author's Master's thesis (see R65-12241), but no reference thereto is given. The method is straightforward and is explained reasonably well although not in enough detail for the novice to be able to use it. In the author's abstract it is stated that "Since reliability prediction is meaningful only when expressed with an associated confidence level, ..." This assertion is not accurate. (A better statement is found in the last sentence of the abstract under R65-12241.) Point estimates are certainly meaningful for any parameter. When confidence intervals are given, the estimates become even more meaningful and so on until the number of pieces of information given about the parameter correspond to the number of independent pieces of data used to arrive at the estimates.

R68-13579 ASQC 824; 433; 831

THE UNCERTAINTY OF SYSTEM FAILURE-RATE PREDICTIONS.

David M. Brender

IEEE Transactions on Reliability, vol. R-16, Sept. 1967, p. 75–81. 5 refs.

The relative uncertainty involved in the prediction of the failure rate of a system is often considerably less than the uncertainty associated with the failure rate of the average component. For example, if we are 60 percent uncertain of the failure rate of each of nine component types, then, at best, we are only 20 percent uncertain of the system failure rate. This result is a consequence of the variety of component types, not the number of each type present in the system. The relative uncertainty associated with the prediction of the number of future system failures is always greater than that associated with system failure rate. As an example, let the uncertainty in system failure rate be 20 percent. If the Poisson process yields a 40 percent uncertainty in the number of failures for an interval t_1, then the actual uncertainty is 45 percent; for a larger interval t_2, if the Poisson process yields 10 percent, the actual uncertainty is 22 percent. The fault is not with the Poisson process, but rather with the assumption that the estimated failure rate can be treated as the true failure rate. Author

Review: This paper contains a number of interesting and useful formulas. They are derived using the standard, well-known statistical facts that if (but not only if) there are n statistically independent variables then the mean of a sum is the sum of the means, and the variance of a sum is the sum of the variances. The expressions in Sec. V, Case 2, do not follow from these simple formulas (which are given by the author early in the text), but instead follow from a little-known formula given by the author in his Ref. 5. The formula can be derived easily from the basic definitions concerning conditional expectations. The use of the standard deviation as a measure of absolute uncertainty and the subsequent use of the central limit theorem should be made with caution, as pointed out by the author in Section VII. As an example, the author states at the beginning of the paper that a system failure rate may have an uncertainty of 180%. This is ordinarily taken to mean that the system failure rate is $\lambda \times (1 \pm 1.80)$. Obviously this is a physically meaningless assertion on the negative side. Thus these uncertainty statements need either to be qualified or to have their very special nature pointed out. In summary, the author's development helps give an insight for engineers into the reasons why a system failure rate can be known more exactly than the failure rates of the individual components. Another approach to the uncertainty of number of failures predicted for a future interval would be to use a confidence interval estimate. This can be done for the case wherein the number of failures in a future interval is estimated from a sample by considering the conditional distribution of the number of failures in a future interval for given total number of failures in an observed test interval (sample) and in the future interval.

R68-13580 ASQC 825; 831; 838

OPTIMIZATION OF SYSTEMS RELIABILITY.

Liang Tseng Fan, Chiu Sen Wang, Frank A. Tillman, and Ching Lai Hwang (Kansas State University of Agriculture and Applied Science, Manhattan, Kan.).

IEEE Transactions on Reliability, vol. R-16, Sept. 1967, p. 81–86. 11 refs.

(Grants NsG-692; NSF-GK-818; Dept. of Interior Grant-14-01-001-523)

(A67-37316)

The purpose of the paper is to obtain an optimum redundancy of the parallel system by a variational technique. The objective function is to maximize the system profit. A simple computational procedure is obtained for the optimum design of the multistage parallel systems by this method. Two numerical examples are given in detail. Author (IAA)

Review: This article apparently has two purposes. One is to introduce a new figure of merit (FOM) for a system and the other is to show how this FOM can be optimized for a particular kind of system configuration. The method chosen for optimization is one that will not be familiar to very many reliability engineers and perhaps not to some of the reliability theoreticians. As such it is not explained well enough, although references are given. The mathematics was not checked in its entirety but appears to be competent. It is not immediately obvious why what way the method is limited, if at all, by the particular FOM chosen. The FOM is a rather special one; e.g., the cost of down time is omitted, and the equation for cost is a simple linear additive one. Statistical independence of the failure events is assumed implicitly rather than explicitly. The method given also seems to be limited to systems of stage-wise configuration in which each stage contains one or more items in active parallel redundancy. Dynamics programming techniques have been used in the paper covered by R66-12815 to optimize the system reliability for serial systems with various forms of redundancy (parallel active, standby, and spares). A similar approach was used in the paper covered by R67-13330 to optimize the reliability of systems of more general configurations using active parallel items and spares. These two approaches are relatively simple to use by means of the appropriate computer program. This paper is primarily for theorists. Many engineering systems of practical import can be optimized by a simple calculation of reliability and FOM for each of several possible combinations since in practice there are very practical limitations on the number of stages which could be paralleled and the allowable number of parallel branches. An engineer who can understand the method and who does need it should, of course, go ahead and use it.

R68-13581 ASQC 824; 412; 433

BAYESIAN CONFIDENCE LIMITS FOR THE RELIABILITY OF CASCADE EXPONENTIAL SUBSYSTEMS.

Melvin D. Springer and William E. Thompson (General Motors Defense Research Laboratories, Santa Barbara, Calif.).
IEEE Transactions on Reliability, vol. R-16, Sept. 1967, p. 86–89. 7 refs.

The problem treated here is that of deriving exact Bayesian confidence intervals for the reliability of a cascade system consisting of N independent subsystems each having an exponential distribution of life with a failure rate which is estimated from life test data. The posterior probability density function of the system reliability is derived in closed form, using the method of the Mellin integral transform. The posterior distribution function is obtained, yielding Bayesian confidence limits on the total system reliability. These results, which are believed to be new for $N > 3$, have an immediate application to problems of reliability evaluation and test planning. Author

Review: This paper is a theoretical one on the use of the Bayesian approach to confidence limits for the reliability of a system. It is limited to a serial system consisting of N independent subsystems each having an exponential distribution of life. It extends the application of Bayesian confidence limits beyond that treated in the many related papers on the topic. The basic approach is the same as in related papers but the posterior system reliability is obtained in closed form through the inversion of the Mellin integral transform. The examples given in the paper aid in understanding the application of the theoretical results. The prior distribution proposed by the authors results in an inconsistency in that the particular form implies that the failure rate is a function of the mission length. This implication is contrary to the use of λ in $R = \exp(-\lambda t)$ as a parameter independent of t. One method of avoiding this difficulty is to use a Gamma distribution on λ, the parameters of which are independent of the mission length. The resulting prior distribution for reliability can then be used in the analysis given in the paper. Although many papers have appeared on the subject of Bayesian techniques, few of them have given applications to *real-world* examples. More papers with such applications would be useful. The controversial aspects of applying the Bayesian method are by-passed in this paper. For those interested in some of the problems in applying the Bayesian techniques to reliability analysis, see RATR items under ASQC Code 433.

R68-13582 ASQC 824; 844

COMMENTS ON "A CAUSAL REDEFINITION OF FAILURE RATE—THEOREMS, STRESS DEPENDENCE, AND APPLICATION TO DEVICES AND DISTRIBUTIONS"

Paul Gottfried (Booz–Allen Applied Research Inc., Bethesda, Md.).
IEEE Transactions on Reliability, vol. R-16, Sept. 1967, p. 89–90.

Defining failure rate as the reciprocal of the device time to failure is considered neither necessary nor natural in some comments on a paper dealing with failure rate theorems, stress dependence, and device and distribution applications. Instead, the term hazard is equated with the definition of failure rate, and device failures are considered to occur due to natural laws of change. The usefulness of statistics and probability are affirmed, even though it is noted that situations can exist in which device degradation proceeds slowly enough to be of no practical consequence during normal equipment service life. It is stressed that the statistical and physical viewpoints toward failure rates are inseparable. M.W.R.

Review: As usual this author has some very pertinent comments to make on a reliability subject. In this case he is criticizing a previous article (see R67-13215). The points made in this letter are good and the uses of statistics are well explained. This letter does not discuss all aspects of the original paper, but the ones covered are treated well.

R68-13585 ASQC 821; 844

Society of Automotive Engineers, Inc., New York.

STATISTICAL PREDICTION TECHNIQUES FOR ANALYSIS OF FIELD FAILURES

Leonard G. Johnson (Gen. Motors Corp., Warren Mich.) Jan 1966 5 p refs Presented at the Automotive Eng. Congr., Detroit, 10–14 Jan. 1966
(SAE Paper-660062; N67-86596)

A technique for predicting field failure rates from customer experience uses a Weibull method of placing failures in correct order within a population of both failed and unfailed items. The method used is referred to as one of suspended items; and the example deals with 46 failures occurring in 7500 vehicle components operating in the field. A Weibull scale is plotted to predict vehicle components failures after various operational periods, with 6% failure predicted within the first 24,000 miles of operation. M.W.R.

Review: This is strictly a cookbook paper, and even though it is short, most of it is devoted to the arithmetic of the example. There is apparently an error in the numbers in Eq. 1. The formula which is used is taken from a book by the author which is cited as his Ref. 2. This paper contributes nothing to the understanding of the formula; it merely tries to show how to use it. Some of the terminology will not be clear to the working engineer; however, he probably does not need to understand it if he can follow the arithmetic in the example and see how the points are plotted. It is unfortunate that not even a brief appendix was given to help explain the formula and why it is suitable. No general formula for median rank is given so that an engineer who has a different set of numbers would have to look elsewhere for that formula. All in all, most engineers would probably be somewhat frustrated if all they had to go on was this paper and they did not have other explanations or the author's book.

R68-13595 ASQC 824

DEVELOPMENT OF A SCATTER FACTOR APPLICABLE TO AIRCRAFT FATIGUE LIFE.

L. F. Impellizzeri (McDonnell Aircraft Corp., St. Louis, Mo.).
American Society for Testing and Materials, Pacific Area National Meeting, 5th, Seattle, Oct. 31–Nov. 5, 1965. 22 p. 15 refs.

Scatter in fatigue test results is one of the more important factors to be considered in predicting a safe service life for aircraft. A scatter factor is developed using statistical techniques to cover the variation in fatigue life among nominally identical specimens subjected to identical loading histories. A procedure is included to handle those cases where the life demonstrated in the laboratory is a least-of-two test result. The statistical analysis is supplemented by a review of numerous constant- and variable-amplitude test results which reveals that the log normal distribution is applicable and the standard deviation of log life is constant within a certain range of average cycles to failure. Fatigue test results of 120 composite aluminum structures are utilized to compute an unbiased sample standard deviation. A significant development of the derived statistical approach is the removal of the necessity to determine confidence intervals for the true mean and standard deviation. This is accomplished by the introduction of a new random variable from which these unknown population parameters vanish. Author

Review: There are two papers associated with this reference. The first is the published version and the second is the mimeo advance copy of the paper. In all cases the final copy is preferred to the advance copy; e.g., it contains the Appendices, does not have the detailed proof of #3 below, and is more readily available. There are four sections of the development part of the paper which have as their main points: 1. Assumption of log Normal

distribution for cycles to failure (N). 2. Determination of an appropriate standard deviation for v=log N. 3. Development of a probability density function (pdf) for $(v-\bar{v})/s$ where s^2 is the unbiased estimate of the variance of v. 4. Mathematical development of the pdf of $(v_1-v)/s$ where v_1 is the least of two independent v's. Item 1 is reasonable for the values of log N under consideration. A few other distributions are equally reasonable. In general there is not enough information to say that any one of them is wrong. Item 2 is less generally accepted; i.e., the conclusion that the variance of v is independent of the true mean over a fairly wide range of the mean. There is certainly nothing wrong with the author's using it in the mathematical analysis which follows; it is tractable and not unreasonable. In the latter part of this section where the data are plotted on a common graph, it would have been worthwhile pointing out that the variance of $x-\bar{x}$ where both come from the same sample (size n) is $(1-1/n)\sigma^2$ since x and $\bar{x}$ are not statistically independent. When x and $\bar{x}$ are statistically independent, as is more usually the case, the variance is $(1+1/n)\sigma^2$ Item 3 is much better in the published paper than in the advance copy. In the former it is pointed out that the estimate of the mean and the estimate of the variance need not come from the same sample when using the t distribution. This is quite correct and it is helpful to have it pointed out to engineers. The advance copy unnecessarily gives a long proof of this theorem—which is well known in statistics. Item 4—the author's notation is confusing both in this section and at the end of the previous section because he uses "s" in his formulas but presumes it to be "σ." Even though they may be equivalent for his purposes because of the large degrees of freedom, if he is considering it to be a constant and not a random variable he should use σ in the formula. In fact, the equations in this section can be true only if σ is substituted for s. One can then use them if he feels he has a sufficiently accurate value of σ. The author asserts in his abstract that the significant development of his approach is the removal of the necessity to determine confidence intervals for the population parameters. Engineers should be warned that nothing magic has been accomplished in the removal of confidence intervals. The Student t distribution, which does not contain the true parameters and is useful for samples from a Normal distribution, was first published in 1908 and its utility has been rediscovered many times since then. Statistics when properly applied will do just what they claim to do—no more, no less. The use of more numbers (e.g., a confidence interval) to describe a situation can give more informative results, but they are not as convenient as a single number and this kind of trade-off must often be made. They can also give less useful results if "sloppy" bounds are used. To readers without some background in probability theory, many points of the paper will be very rough going. The contributions that the author has made can be summarized as: (1) v = log N can reasonably be presumed to be Normal over a reasonable range of v, (2) the variance of v is reasonably independent of the true mean over a similar interval, (3) in the Student t distribution, engineers are reminded that the two variables need not be from the same sample, (4) the author shows a particular variable having the t distribution which can be useful, and (5) a variable, related to the least-of-two, is introduced and analyzed.

R68-13602 ASQC 824; 433

RELIABILITY TESTING IN A BAYESIAN CONTEXT.

David M. Brender (Systems Prediction Analysts, New York, N. Y.). *(Institute of Electrical and Electronics Engineers, International Convention, New York, N. Y., Mar. 21-25, 1966, Paper.)* *IEEE International Convention Record*, vol. 14, pt. 9, 1966, p. 125-136. 3 refs.
(A66-24670)

Consideration of a system with an unknown failure-rate parameter which is to undergo a reliability test of the accept-reject variety. The concern is with the construction of measures of error and validity of the test (given information on the system) as well as with the development of measures of the quality of the system (given information on the test). It is noted that it is within a Bayesian context that it is possible to directly satisfy these dual needs of the producer and consumer. The concern is also with predicting future performance conditional on system information and possible test results. Confidence statements are constructed for all measures. A measure of the overall error of a test is also defined and minimized. Bayesian techniques permit the complete numerical evaluation of test, quality, and performance measures as well as confidence statements before and after a test. IAA

Review: A large number of useful formulas are presented in this paper. The formulas are based on Bayesian techniques and provide conditional and unconditional probability statements relating system quality, properties of acceptance tests, overall errors of acceptance tests, reliability estimates, and confidence estimates for the above measures. The formulas are hand-written and generally easily read, though not as convenient for the reader as a typed version would be. A check of the formulas indicates that they are correct except for a minor error in Equation (5.4) on p. 129, which should read

$$P_{G|R} = \Pr\{\Lambda \leq \lambda_c | N_t > n\}.$$

No derivations of the results are given; however, almost all of the formulas follow immediately from definitions and only a few would require a derivation. The "pros" and "cons" of Bayesian concepts are discussed with respect to the measures of interest. Although the paper would be considered a theoretical one by many readers, it has a broad range of possible applications, given that one has a problem concerning failure rates which can be put into a Bayesian context. The paper should be of particular value to workers in the field concerned with acceptance tests from the standpoint of the producer, consumer, and test designer. The catalogue of formulas will be a good reference for use in dealing with such problems. The author in a private communication has pointed out the following typographical error in the paper: "Equation (15.5) should read $E\{\epsilon_q(N_t)\} = \epsilon$."

83 DESIGN

R68-13549 ASQC 832; 760

THE HUMAN FACTOR IN INDUSTRIAL TESTING.

H. J. Lavender, Jr. (General Dynamics Corp., Electronic Div., Rochester, N. Y.).
Materials Research and Standards, vol. 7, Sep. 1967, p. 397-399. 13 refs.

A case history is presented in which human engineering methods were used to modify industrial testing procedures by increasing the probability of detecting defective parts. Human limitations and errors were considered in relation to industrial testing procedures and consequent equipment failures. It was found that the human eye could not function fast enough to reliably record the necessary data during vibration testing of impact detectors. The solution was to install a camera to record results, which were observed by the technician after the film was developed. Use of the camera and change in procedures after a task analysis resulted in potential reliability reaching inherent design reliability. M.W.R.

Review: The philosophy stated in this article is a good one. The comments on programs such as zero defects are well taken.

Any test for defectives vs. nondefectives is important for reliability and, from many informal reports at least, a very great percentage of the NASA missile failures are due directly to gross human failures. There is some mathematics in the early part of the article which is erroneous. Fortunately it is not critical to the main point of the article. Nevertheless this kind of qualitative mathematics appears in the literature all too often in reliability calculations. The difficulties and errors are (1) first writing down an equation of probabilities rather than a statement about events, (2) poor definitions (or implied definitions) of events, and (3) consequent invoking of the product rule where it is not necessary (the product rule implies statistical independence among the events whereas a more useful formulation often does not require the product rule). The author's Eq. 1 is obviously in error since if (1) manufacturing's failure to meet specifications has a high probability, (2) testing efficiency is high, and (3) inherent design reliability is low, then the potential reliability could be negative according to the formula. But properly formulated probabilities can never be negative. A useful formulation of the author's problem is given below (since the problem was not completely defined by the author it is difficult to tell if it is exactly the one he had in mind, but it appears to be quite close). Let $d' \equiv$ event of a designed-in defect, $m \equiv$ event of a manufactured-in defect, $t' \equiv$ event of a defect passed through the test, and $s' \equiv$ event of a defective product escaping, where the prime indicates a complement (negative) and the notation is chosen to be similar to the author's. Then $s' = (m+d')t'$; i.e., for a defective product to escape, there must have been "a designed-in defect and/or a manufactured-in defect" together with a "defect passed through the test."

$$\Pr\{s'\} = \Pr\{(m+d')t'\} = \Pr\{t'|m+d'\}\Pr\{m+d'\}$$
$$= (1-T)[\Pr\{m\} + \Pr\{d'\} - \Pr\{m|d'\}\Pr\{d'\}]$$

where $1-T \equiv \Pr\{t'|m+d'\}$ is the probability of a defect being passed, given that there is a defect to be judged. (When written as a conditional probability there is no need to invoke the "product rule"; furthermore, the probability is defined more accurately.) If m and d' are statistically independent (this may be a severe restriction if bad designs are easier to mismanufacture than are good designs) and

$$M \equiv \Pr\{m\},\ 1-D \equiv \Pr\{d'\},\ 1-S = \Pr(s'),$$

then

$S = D(1-M)(1-T)+T$, which is a far cry from the author's $S = D-MT$.

The answer is complicated enough to show that it would have been difficult to write it down by inspection. If an author wishes to use qualitative language it is best not to use equations at all.

R68-13550 ASQC 830

PROGRAM CONTROL EXTENDS PERIPHERALS' MTBF.

A. B. Linsky (Sylvania Electronic Systems, Waltham, Mass.).

Control Engineering, vol. 14, Sep. 1967, p. 95–96.

Mean-time-between-failure rating of computer peripherals can be increased by switching them on only when they are actually needed. A program control method is suggested for the reduction of on-time, and a special subroutine called by the executive program in the computer is the key to program control of the peripherals. This subroutine has a timing sequence that allows time for startup operations such as the motors coming up to speed or the peripheral's electronics warming up. Since the same program controls data transmission to and from the peripherals, it can also control the time at which the device is to be turned off. There is no indication that the on and off switching of the peripherals reduces their lifetime; and transients generated by the switching circuits do not adversely affect the computer because the critical leads are filtered and shielded. The presented technique, which uses a combination of hardware and software, was implemented in the command and control system for Minuteman. M.W.R.

Review: This article shows an engineering application for achieving high reliability. The basic idea is to reduce the on-time of those mechanical items whose life is consumed by being on, and which suffer no deleterious effects from the turn-on/turn-off process. The reduction in on-time is accomplished by program control. Even though extra electronic hardware was required, it presumably has a life much longer than the mechanical items it is designed to save. One of the main things illustrated by this article is that for high reliability, when the chips are down, rules of thumb should be discarded and each one of the options analyzed on its own merits. The fact that this particular solution may not always be a solution is irrelevant to the problem at hand.

R68-13555 ASQC 832; 810

ARINC Research Corp., Annapolis, Md. Science Center.

HUMAN RELIABILITY PROGRAM FOR THE SATURN V LAUNCH VEHICLE GROUND SUPPORT EQUIPMENT

Harald R. Leuba Oct. 1965 33 p refs *Its* Publ.-294-25-34-539

(Contract NAS8-11087)

(NASA-CR-83119; N67-21168)

The prediction and evaluation of human reliability for the Saturn V launch vehicle ground support equipment are discussed. The investigation is divided into five major sections: (1) the purpose of the human reliability program, (2) a system description, (3) possible techniques for prediction and evaluation, (4) limitations of the study, and (5) recommended actions. The material presented does not solve human reliability prediction and evaluation problems, but it does describe those problems and provide quantitative recommendations on how they could be solved. Information requirements and alternative analytic procedures are listed. Author

Review: This paper is a preliminary analysis of the human reliability problems that could be associated with the equipment. One of the big contributions the author makes is his listing of the assumptions about the behavior of people and machines which might otherwise remain implicit and thus cause difficulty. There is not enough information about the system to solve any of the problems that are raised, as the author states, but the raising of the problems itself is a worthwhile function. Order of magnitude computations are made about the relative likelihood of certain kinds of failures; some are eliminated as being virtually impossible; others may be quite likely. The philosophy as revealed by the questions is worthwhile reading even for those not concerned with this particular system.

R68-13556 ASQC 838

Air Force Systems Command, Wright-Patterson AFB, Ohio. Flight Dynamics Lab.

IMPACT OF RELIABILITY REQUIREMENTS ON FLIGHT CONTROL DEVELOPMENT

Frederick R. Taylor Mar. 1967 28 p refs Presented at NATO–AGARD Guidance and Control Panel, Paris

(AD-648563; N67-27461) CFSTI: HC$3.00/MF$0.65

The advent of high performance aircraft has placed more dependence on automatic flight control functions. Because of this the control system is required to not only be highly reliable but also fail operational to provide maximum safety-of-flight capability. The major impact of these reliability and safety requirements on flight control development is that redundancy will definitely be required for advanced high performance vehicles because it is the only means of obtaining fail operational performance. Design techniques are presented which can be used toward developing completely fail safe aerospace vehicles. Author (TAB)

Review: This paper will be of interest to designers of aerospace systems which must be capable of continuing to operate in the presence of some component failures. The latter logically implies redundancy. Several redundancy techniques are described, both for electronic components and for non-electronic components. It is noted that with the advent of miniaturization, weight and size constraints are less of a problem with electronic components than with other components because of the physical outputs required. The paper is a good summary of design techniques for high reliability and safety, clearly illustrated with tables and figures. The discussion is keyed to 10 references, which will be useful to those who desire more details.

R68-13560 ASQC 836
Martin Co., Baltimore, Md.
ELEMENTS OF DESIGN REVIEW FOR SPACE SYSTEMS
R. E. Boss and C. H. McGaffin Washington, NASA, 1967 62 p refs
(Contract NASw-1128)
(NASA-SP-6502; N67-33400) CFSTI: HC$3.00/MF$0.65

Design reviews performed by space system contractors are detailed, along with some of the reviews and tradeoffs conducted by the customer to satisfy overall program requirements. Detailed objectives of the design review are concerned with evaluating design capability in terms of total system requirements; identifying process control, production, and procurement problems; determining if design conforms to the specifications required for operational use; and optimizing design within functional performance requirements. Elements of a design review are review team makeup and responsibilities, customer participation, frequency of review, data inputs and outputs, and continuity and followup procedures. Review categories discussed deal with preliminary design, prepackaging and pre-release design, acceptance, and special purpose reviews. Applications and costs of design review for space systems are also included in this manual intended as an aid for instructing technically trained personnel in design review implementation and evaluation. M.W.R.

Review: A large expansion is presented in this guideline document on what is covered by essentially a paragraph or so in NASA reliability specification NPC 250-1: This publication emphasizes that NASA intends that design reviews should be a significant feature of project management's system of checks and balances. Guidelines are established to relate the extent of the necessary design reviews to the complexity and significance of the program. NASA has something to point to with this document when discussing design reviews, and contractors have something with which to compare their practices. Of value in this publication are cost figures associated with design reviews. Tables on costs indicate that design reviews are intended to cost approximately 1% to 2% of the total engineering cost. NASA has recently released a publication similar to this but broader in scope (see R67-13367). It covers the entire subject of reliability programs and has several pages devoted to design reviews.

R68-13569 ASQC 831; 838
A COMPARISON OF SOLID STATE AND RELAY REACTOR SAFETY SYSTEMS.
George A. O'Sullivan (Nuclear Utility Services, Inc., Washington, D. C.).
IEEE Transactions on Nuclear Science, vol. NS-13, Feb. 1966, p. 420–425.

Solid state circuits demonstrating fast speed of response, miniaturization, and low power consumption have been replacing relay circuits in the logic portion of recent nuclear reactor safety systems. Some of the advantages of relay logic, such as circuit isolation, minimum number of parts, and low cost have been lost in the transition. A solid state and a relay safety system are described, and the application and merits of each are developed. Both system designs can meet the principal safety criterion of having the capability to take safety action when required under all operating conditions and with the presence of any one fault either within or outside the safety system. Secondary criteria used to compare the merits of each system are operability (freedom from false shutdowns), simplicity in testing, ease of maintenance, speed of response and cost. Reliability considerations include mode of component failure, frequency of testing, and the need for developmental testing. Author

Review: This paper discusses the reliability problems associated with relays vs. semiconductors in the logic portions of nuclear reactor safety systems. There are no clear-cut conclusions—contrary to what it is easy to expect from the early part of the paper and the title. The reason that there are no such clear-cut conclusions is, of course, that they do not exist. The discussion is qualitative and does not seem as if it would be vitally helpful to a design engineer. It does give a good discussion of some of the broad principles and techniques available, such as kind of logic, but there is still much implementing for the design engineer to do. Redundancy is a prime and defined requirement for either system. While testing is mentioned in general, there is no discussion of how automatic this testing may be. The paper has little to contribute in the reliability discipline outside its stated field.

R68-13576 ASQC 831; 844
PREDICTION AND ENGINEERING ASSESSMENT IN EARLY DESIGN.
W. P. Cole (General Electric Co., Ltd, Applied Electronics Laboratories, Stanmore, Middx., England).
(Institution of Electronic and Radio Engineers, and Institution of Electrical Engineers, Symposium on Engineering for Reliability in the Design of Semiconductor Equipment, Hatfield College of Technology, Hatfield, Herts., England, May 13, 14, 1965, Paper.) Radio and Electronic Engineer, vol. 31, Jan. 1966, p. 33–46.
(A66-15948; A66-21858)

The paper discusses the steps which could be taken in the early design stages to predict, assess and then verify the reliability of the component parts of the system. Prediction of "mean time between failures" of electronic equipment is dealt with in particular. The Advisory Group on Reliability of Electronic Equipment (AGREE) type of testing carried out by the manufacturer to determine the reliability of his final product is described in some detail in an appendix. Author (IAA)

Review: This is the same paper as covered by R67-12985. It was presented at a conference and later published in two different journals. The comments in the original review still apply.

R68-13578 ASQC 831; 530; 612; 824
PERFORMANCE SIMULATION INVOLVING CORRELATED PART CHARACTERISTICS.
A. Carl Nelson, Jr. (Research Triangle Institute, Statistics Research Div., Reliability Group, Durham, N. C.) and James R. Batts (Research Triangle Institute, Statistics Research Div., Durham, N. C.).
IEEE Transactions on Reliability, vol. R-16, Sept. 1967, p. 72–75.
(Contract NASw-905)
(A67-37315)

In the analysis of an electronic circuit containing component parts on which two or more measurements are made there is the need for treating correlated part characteristics. In a performance

simulation analysis using a digital computer, the correlated variables must be generated with the appropriate correlations. A method for generating a set of normally distributed variables with a given correlation matrix is presented. The method is based on an algorithm used in the square root method for solving a system of linear equations. The procedure is applied to a linear amplifier, for which the h-parameters of the equivalent dc circuit analysis of the transistor are a good example of correlated part characteristics. The method has been written in FORTRAN and the computations could be performed on almost any digital computer. Author (IAA)

Review: The mathematics for this paper appeared in the final report of the referenced contract. The article is important not only for the presentation per se of the mathematics but in emphasizing to the reliability engineer that correlations can and must be taken into account. In a paper written for engineers who are not accustomed to the technical statistical usage of certain terms, it is wise to use the term linear correlation rather than correlation. The engineer is likely to associate correlation and dependence, whereas, to the statistician, the correlation coefficient is a measure of the strength of a linear relationship. The engineer will also have to remember (as stated in the text) that this procedure is good only for situations wherein all of the variables have Gaussian distributions. In the example the random variables ϵ and δ do not include inherent variations in the component parameters since these are included in the formula. The reference to predicted mean gain is ambiguous. The predicted means are for given values of the component parameters, h_{fe}, R_3, h_{oe}, R_1, R_2, and R_4; that is, a mean over ϵ and δ, the measurement errors and model inadequacies. It would have been helpful to show how large the error would have been if the linear correlations had been neglected.

R68-13590 ASQC 832; 838

Society of Automotive Engineers, Inc., New York.

ENHANCEMENT OF SPACE POWERPLANT RELIABILITY BY CREW ACTION

P. Duchon and L. K. Petersen (Aerojet-Gen. Corp., Azusa, Calif.) 4 Oct. 1965 18 p Presented at the Natl. Aeron. and Space Eng. and Manuf. Meeting, Los Angeles, 4–8 Oct. 1965

(SAE Paper-650810; N67-86591)

The man-powerplant reliability interface is discussed with emphasis on manned vs automatic sensing and control. Judgment and recognition of powerplant performance and the ability to correct abnormal conditions with man included in redundant-component systems results in higher system reliability. An expression for a man-plus-automatic-redundant-component subsystem is presented that gives the subsystem reliability vs the reliability of its parts. Author

Review: This paper is a documented plea to consider man as part of a maintenance/redundancy loop for spacecraft power plants. The kinds of things that men can do are compared with the kinds of things that power plants need to have done to them. There is maintenance, both preventive and unscheduled, and sensing and control; men can either supplement or replace automatic execution of these functions. Any long-range plan should certainly include a study of this option and this paper calls attention to it. The difficulties arise when trade-offs must be made. That is, there are many things competing for the crew's attention. Which ones should be allowed? For a given size, weight, cost, etc., which is the more effective method of maintenance and control—a man or a machine? Even though the crew can do some of these things effectively, the trade-off for various kinds of optimization may result in the crew's actually not doing them, but having them performed in some other way. This would be especially important if it meant a possible reduction in the number of the crew. But in order to make trade-off studies, the design and planning engineers must be aware of the kinds of things they can trade off, and this paper serves as a help in that direction.

R68-13598 ASQC 830; 612

DESIGN AND USE OF FAULT SIMULATION FOR SATURN COMPUTER DESIGN.

F. Hardie and R. Suhocki (International Business Machines Corp., Federal Systems Div., Electronics Systems Center, Owego, N. Y.). *In: WESCON/66; Western Electronic Show and Convention, Los Angeles, Calif., August 23–26, 1966. Technical Papers. Session 21—High-Availability Computer Systems.* Los Angeles, Western Electronic Manufacturers Association, 1966. 22 p. 4 refs.

Discussion of the Saturn fault simulator, a system of programs to be executed on an IBM 7090 computer. Two objectives of the simulator are verification of the logic design of the Saturn computer and analysis of the effects of solid and intermittent faults. A significant characteristic of the simulator is full central-processing-unit simulation while containing in one 32K memory the complete compiled logic simulator and a simulated Saturn memory module as well as interface data. The programs are described in the same order that they would be normally executed, and the application of the simulator is outlined. IAA

Review: An extensive and well illustrated description is given of a system of programs for use in fault simulation on the Saturn computer. Approximately the first half of the paper is devoted to a description of the programs. The second half describes the use which was made of the simulator as an aid in evaluating computer operation in both normal and failure modes, the verification of the logical integrity of the computer circuits, and the evaluation of proposed engineering changes. The advantages of simulation over hardware testing for preliminary engineering are indicated, as are the limitations of this approach. The detail given is sufficient to present a clear picture to those who are knowledgeable in this field.

R68-13600 ASQC 838

CIRCUIT FAILURE ASYMMETRIES FOR RELIABILITY IMPROVEMENT IN DIGITAL CIRCUITS.

Herbert D. Goldman (Hofstra University, Hempstead, N. Y.). *(Institute of Electrical and Electronics Engineers, International Convention, New York, N. Y., Mar. 21–25, 1966, Paper.) IEEE International Convention Record,* vol. 14, pt. 9, 1966, p. 115–118. 3 refs.

(A66-24668)

This paper reports on a redundancy method for obtaining reliability improvements for digital circuits. The method depends upon the fact that common digital circuits will not fail symmetrically—i.e., more often than not a given circuit will have a high (or low) voltage polarity when it fails. Two analyses, one general and the other specific, show this reliability method is competitive with the triplicated majority voting technique while using less equipment. Author (IAA)

Review: A clearly-written description is given of a redundancy method for obtaining an improvement in the reliability of digital circuits. The usual assumptions of independence and exponential distribution of failure times are made. The redundancy technique uses a priori information concerning the mode of failure of the circuit. Apparently this technique has not been described in recent reliability literature. The reliability using this method of adding redundant elements is compared with that of triplicated majority voting. It would also be of interest to consider the relative down-times resulting from these two methods of applying redundancy. This paper should be of particular value to digital circuit design engineers.

84 METHODS OF RELIABILITY ANALYSIS

R68-13557 ASQC 844; 838
Columbia Univ., New York. Inst. for the Study of Fatigue and Reliability.
ON FATIGUE FAILURE OF A MULTIPLE-LOAD-PATH REDUNDANT STRUCTURE
A. M. Freudenthal and M. Shinozuka Jun. 1965 29 p refs
(Contract Nonr-266(91))
(TR-20; AD-467857; N65-33734)

It is difficult to evaluate the survivorship or reliability function of a structure subject to fatigue consisting of a number of members from the survivorship functions of a single specimen that can be obtained from experiment. An attempt is therefore made to establish the upper and lower bounds of such a survivorship function under the assumption of constant amplitude fatigue and equal distribution of the load among the existing members, approximating the real process of the failure by Markovian processes. A numerical example employing the data of fatigue tests performed on 7075 Aluminum alloy single specimens indicates that the order of magnitude of the life of a composite structure can be reasonably well predicted by the estimate of the bounds according to the present method.
Author

Review: This paper makes no assumption about cumulative damage and therefore is more general than earlier papers in this series (see, for example, R66-12468, R66-12538, R66-12599, R66-12747, and R67-13107). The price to be paid for this generality is that the problem itself cannot be directly solved and so bounds for the survival probability are calculated. It is interesting that in the case of a few specimens' being redundant, the lower bound is just the probability of the first failure. In the text example the life is predicted to within a factor of 10 for probabilities less than about 0.9. In the conclusions the authors are concerned about the anomalous behavior of the failure-probability vs. number-of-cycles curves at constant stress. The trend shows they will cross somewhere and they wish to make further assumptions to prevent it. The only assumption that need be made of course is that extrapolation to these very low probabilities of failure is not valid—that the formulas for the parameters of these lines hold only in the range for which there is data. The problem treated in this paper, while not earth-shaking, may well be helpful to engineers who must make fatigue calculations on redundant structures.

R68-13561 ASQC 844
National Aeronautics and Space Administration, Washington, D. C.
ELECTRIC CONTACTS. PART IV: RELIABILITY OF CONTACTS
B. S. Sotskov, I. Ye. Dekabrun, G. Ya. Rybin, T. K. Shtremberg, N. A. Belozerova et al Dec. 1965 p. 376–437 refs Transl. into ENGLISH of the book "Elektricheskiye Kontakty" Moscow, Izd. Energiya, 1964 Proc. of 3d All-Union Conf. on Elec. Contacts and Contact Mater., Moscow, 11–14 Dec. 1962
(NASA-TT-F-339; N66-13286; N66-13287; N66-13288; N66-13289; N66-13290) CFSTI: HC$3.00/MF$0.65

Proceedings of the All-Union Conference on Electric Contacts that deal with reliability aspects are reviewed. One paper deals with reliability of the open circuit, contact closure, and contact release; in another, operational data are presented to show the reliability of electromagnetic relay contacts and relay failures are tabulated according to their causes. The useful life of platinum–iridium relay contacts is considered in terms of load current, and methods of determining useful life are discussed. Life tests and the establishment of norms are also reported. Attention is given to the determination of norms from the basic electric parameters of connector contacts. The transitional resistance of the contact is discussed, and norms are evolved; and the thermal state of the multiple-contact snap connector is considered. A system for recording failures is presented in terms of ac and dc operations. M.W.R.

Review: This review covers Part IV of the Proceedings, which deals with Reliability of Contacts. The actual conference was held in late 1962, the Proceedings were published in Russian in 1964, and notice of the availability of the NASA translation appeared in 1966. The first paper "The Reliability of the Electric Contact" (N66-13286) deals with simple conceptual models for contact resistance. It explicitly assumes statistical independence and Normal distributions for all of the events being considered. The statistical independence assumption is probably especially restrictive. The results are largely in terms of algebraic equations. This paper may be of interest to the theorist on the subject of contacts, but is unlikely to be of concern to anyone else. The second paper "The Reliability of Electromagnetic Relay Contacts According to Operational Data" (N66-13287) is rather short and gives some numbers on relay failures and breaks them down into fractions for different kinds of failure. Presumably the relays under consideration here were small telephone-type relays or equivalent, but there is no way of knowing exactly. Again, this paper would be of little value to relay application. The third paper "The Useful Life of Platini–Iridium Relay Contacts as a Function of Load Current" (N66-13288) gives the results of a life test on a particular relay wherein the load current was varied. The switching network is shown and the details of fault isolation are given. A log Normal distribution was found for the contact life, ignoring infant and gross wearout failures. Since the paper does not deal with relays available to American designers, the results will be of possible interest only to theorists. Some attempt was made to go into the reliability physics of the relay—the influence of the construction and control circuits. The fourth paper, "Determining Norms from the Basic Electric Parameters of Connector Contacts," (N66-13289) is an approach from reliability physics to create some conceptual models for analysis of contacts. Temperature is considered to be important and much of the effort is on the heat transfer problem. The geometry of the connector is also considered. Some actual numerical calculations are made. Again the material here is not for designers. The fifth and final paper, "A System for Recording Failures," (N66-13290) deals with some vacuum tube circuits which are useful in recording the exact occasion of failure when a particular contact was opened or closed for various kinds of operation. This paper might be of concern to those who run life tests on relays. All in all this collection of papers will probably be of use only to the contact specialist who wishes to be sure that he is acquainted with what is going on everywhere so that he is sure nothing has been overlooked.

R68-13572 ASQC 844; 775
NON-LINEARITY MEASUREMENTS IMPROVE RESISTOR RELIABILITY.
P. L. Kirby (Welwyn Electric, Ltd., Bedlington, England).
Electronic Components, vol. 8, May 1967, p. 511–515. 1 ref.

Measurements of third harmonic index were used to determine if nonlinearity in fixed resistors could be used to indicate potential failure. Four thousand tungsten oxide film resistors considered to be of high reliability were graded into nine groups according to

the level of current noise; and frequency distribution of noise index as well as load test grouped frequency tables illustrating behavior of each of the nine groups over a period of 10,000 hr are presented. The latter indicated noise measurements to be a useful indication of subsequent reliability, and so a correlation was made between the noise index and third harmonic index for a test batch of 410 resistors. Nonlinearity screening was found to be more efficient than noise screening in the elimination of catastrophic failures, and the relative numbers of resistors accepted or rejected by equivalent screening limits for noise and third harmonic index are tabulated. M.W.R.

Review: It is very easy to get the feeling after reading this article that there probably is not a great deal of difference between the efficiencies of third-harmonic screening and current-noise screening as far as improving reliability is concerned. The differences that were observed are easily attributable to chance and the article is not written so as to show a strong bias for one or the other in terms of efficiency. The author asserts, and apparently correctly so, that the third-harmonic measurement is much easier to make than the noise measurement and therefore is to be preferred, especially on a production line. The increase in reliability is due to eliminating both catastrophic failures and units which may drift severely. There is apparently an appreciable fraction of good resistors rejected along with the bad ones in order to make substantial improvements in reliability. The developers of this equipment in some of their papers (see, for example, R67-13486) appear to have claimed much better efficiency for their device than can be gotten from current-noise screening. The present article refers only to oxide film resistors. While one may be enthusiastic after reading this article and wish to try it on other products, there is no guarantee that the results are directly transferable. In a private communication the author has stated that the technique is finding use in application to all current types of film resistors. Any means for improving reliability by using nondestructive tests should be investigated. Those which are both very efficient and very inexpensive should then find wide application. Nonlinearity measurements or in particular the generation of third-harmonic voltages should be pursued further on the nominally linear components to see what it can do. It is, of course, restricted to nominally linear components, viz., some kinds of resistors, non-electrolytic capacitors, and air-core inductors.

R68-13574 ASQC 844; 822; 872

UNSERVICEABILITY ANALYSIS.

A. B. Howell

Canadian Aeronautics and Space Institute Journal, vol. 11, Nov. 1965, p. 335–345. 6 refs

(A66-13107)

This paper continues the description of Unserviceability Analysis that began with a paper on Unserviceability Costing. The paper divides into two parts. A more or less conventional treatment of general unserviceability characteristics of a fleet of aircraft is described in part one. Part two deals with reliability of individual component installations, in which the treatment is oriented toward mechanical failure and its dominant feature of "wear-out." The Erlang is used to simulate the reliability of component-installations with this characteristic mode of failure. The choice of Erlang affords some simplification that other functions do not provide, and examples of calculation and plotting are provided to display this facility. Author (IAA)

Review: This paper discusses some of the practical aspects of collecting and using failure data on aircraft. One of the main objects of the data collection program is to provide as long a time as possible between scheduled maintenance activities. Thereby one can reduce costs and increase the up-time, and perhaps even increase the reliability. The probability functions used to analyze the data are the hyper-exponential and the Erlang distributions (the exponential is a special case of each); these have decreasing and increasing hazard rates respectively. Apparently it is difficult to find a tractable expression which has appropriate non-monotonic behavior of the hazard rate. Therefore, during the life of the equipment, different formulas must be used for the reliability. As the author states, these distributions find considerable application in queueing theory but are not often used in the reliability literature. He does give the Erlang distribution and shows that it is similar to the equation for parallel redundancy wherein each element has the same constant hazard rate, but he does not give the hyper-exponential distribution in the text. The paper will be most useful for those engineers who are trying to do quite similar analyses. It will be difficult to make use of this material in other areas. This paper could be called an expanded case-history type of presentation.

R68-13583 ASQC 844; 716; 770

AN AGING AND TESTING FACILITY FOR HIGH-RELIABILITY TRANSISTORS AND DIODES.

Richard L. Odenweller, Jr. (Western Electric Co., Inc., Reading, Pa.).

The Engineer, vol. 11, Jul. 1967, p. 20–29.

A specially-designed aging and testing facility is described that has a capacity for testing 25,000 semiconductor devices manufactured for use in submarine cable repeaters. These devices are periodically tested for six months within temperature-controlled modules, which permit precise measurements without operator handling. The test sequences are automatically performed with regularly calibrated test equipment mounted on movable test carts; and the resulting data are analyzed by a preprogrammed facility computer. The aging and test programs are tabulated for milliwatt and power transistors, 15-volt and 10.8-volt regular diodes, dual rectifier, and dual PNPN switch; and a typical test sequence is shown. The surveillance system that constantly monitors the facility is described, as is the other support equipment. Operating results indicate that the aging environment of the facility is stable and that test data are accurate. M.W.R.

Review: This paper discusses a test system which can be regarded as accelerated testing in reverse. Since the stresses cannot be higher than might be encountered in practice, very sensitive measurements of the parameters are undertaken to determine the small changes which occur. The purpose is to eliminate those transistors whose parameters have unpleasant trends. The article gives a very general description of the system, of the accuracies required, and the special procedures, and finally mentions some of the unanticipated problems associated with the start-up and running of the facility. This kind of approach has been mentioned in the literature before, especially for high-reliability satellite parts, but none seem to have carried the testing to the extremes of sensitivity that are mentioned in this paper. It is interesting to note that the transistorized repeaters in which these parts will be used will not include redundant signal paths. There are no allowed failures in any of these units for 20 years. It shows that not everyone is in agreement with the dictum that extremely high reliability can be obtained only by extremes of redundancy. This approach to accelerated testing requires much more finesse than the increasing-of-the-stress kind which is ordinarily associated with the name and therefore will not replace it except in the most compelling of circumstances.

R68-13584 ASQC 844; 775

ASPECTS OF USING INFRARED FOR ELECTRONIC CIRCUIT DIAGNOSIS.

Ruth A. Herman (USAF, Systems Command, Research and Technology Div., Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio).
(Society for Nondestructive Testing, National Conference, 26th, Chicago, Ill., Oct. 31–Nov. 3, 1966, Paper.) *Materials Evaluation,* vol. 25, Sept. 1967, p. 201–205. 10 refs.
(A67-39631)

Discussion of IR applications, directed primarily toward the location of faulty electronic components on printed-circuit boards. Other valuable applications of IR in electronic-equipment diagnosis include establishing topological design criteria, acceptance testing, quality control, operational testing, status monitoring, and failure prediction. The use of IR in acceptance testing for quality control and for circuit checkout will enable the location and rejection of many electronic units that are due to fail because they contain faults not now detected by conventional tests. IAA

Review: This is a slightly reorganized version of the paper covered by R67-13235. The graphics, which were not reproduced in the DDC copy (AD-642 428) previously reviewed, appear in this one. The paper is limited to a discussion of circuits made on printed circuit boards. The conclusions of the author appear substantially more conservative than one sometimes sees in the literature. In particular, the sense of the article is that the method is promising in many circumstances; but it is easy to infer that much work remains to be done before this kind of infrared diagnosis is put on a production basis. The author conscientiously has listed many of the problems associated with infrared diagnosis—something else not always done. The paper will be of value to those who are interested in doing applied research in this area, and to those who have the time to develop the method further for their own electronic circuits. No discussion is given of resolution, which would be important, for example, in analyzing integrated circuits.

R68-13587 ASQC 846
Society of Automotive Engineers, Inc., New York.
A.M.C. WARRANTY PREDICTIONS
A. J. Junker (Am. Motors Corp.) Jan. 1966 6 p Presented at the Autotmotive Eng. Congr., Detroit, 10–14 Jan. 1966
(SAE Paper-660061; N67-86594)

Total warranty expense predictions for an automobile manufacturer are discussed, and a running average technique based on the ratio of cumulative costs and miles driven during the warranty period is presented. This technique is not considered too accurate on a single component or a group of components that have increasingly high repair rates; and in the event of such occurrences, other statistical tools must be employed. Studies indicate that warranty expense per car can be represented by a linear relationship throughout the warranty life. M.W.R.

Review: This paper explains a relatively unsophisticated method for estimating the warranty cost for cars. In contrast to two other papers presented at the same meeting, this one does not use a Weibull distribution for this purpose. It will be of most interest to those who are engaged in similar prediction activities. According to the explanation, this prediction is not used to give feedback to the engineering and production departments on changes, but merely to estimate the expected value of the cost per car of the warranty. Perhaps other programs in the company provide the technical feedback.

R68-13589 ASQC 846
Society of Automotive Engineers, Inc., New York.
RELIABILITY PREDICTION FROM WARRANTY DATA
B. H. Simpson (Ford Motor Co., Dearborn, Mich.) Jan. 1966 8 p refs Presented at the Automotive Eng. Congr., Detroit, 10–14 Jan. 1966
(SAE Paper-660060; N67-86592)

Warranty data analyses can be used to predict product reliability; identify problem rates between various assembly plants, months of production, vendor sources, and vehicle options; and describe types of complaints for automobile components. Methods used to analyze incoming field data and to process results into useful forms for tracking field performance are presented. Analyses are Weibull distributions programmed on a computer; and mileage analyses cover each component of an automobile. It is considered that the warranty data from six months or even less field service can be used to predict product reliability, lifetime warranty cost, and repair rates for as long as two and one-half years further operation. M.W.R.

Review: This paper is descriptive rather than tutorial; that is to say, one could not create a similar system after reading this paper. It is interesting that the calculation method shown here for plotting the failure points on the Weibull paper is rather different from that given in the Johnson paper at the same meeting. Many of the Weibull slopes shown in the examples are appreciably less than 1 which means that the hazard rate is fairly-rapidly decreasing. The exact details of the analysis are probably unimportant. The important fact is that there is a technique available for using the field service data and that it provides the engineering department (and others) with valuable information which can be used to improve the product. No mention is made in this paper of the fact that the field service reports may not be an accurate description of what actually happened. It is apparently not unknown that distributors will falsify these records for various reasons other than gross avarice. This paper would be of qualitative interest to both engineering and management people who either do not have such a system or wish to compare this system with their own.

R68-13591 ASQC 844; 775
American Society of Mechanical Engineers, New York.
DYNAMIC NONDESTRUCTIVE MONITORING TO DETERMINE MECHANISMS OF FAILURE
Warren J. McGonnagle (IIT Res. Inst., Chicago) May 1966 7 p refs Presented at the Design Eng. Conf. and Show, Chicago, 9–12 May 1966
(ASME Paper-66-MD-48; N67-86590)

Nondestructive testing methods and techniques are discussed in terms of applications for the dynamic monitoring and determination of the mechanisms of failure. Fatigue, fatigue cracks, and fractures are considered; and spot welds are mentioned as nondestructive testing applications. A gamma-ray and X-ray imaging system, ultrasonic wave monitoring, high speed photography, flash radiography, thermal radiation are also mentioned. M.W.R.

Review: This paper is largely a brief review of some of the techniques for nondestructive monitoring of fatigue cracks. A few other mechanical applications are mentioned, but the nondestructive testing of electronic components, for example, is not covered. Many references are given, especially in the area of fatigue crack propagation. These techniques are rarely useful for field inspection, but rather are laboratory procedures. One of the more important sentences in the paper is, "Unfortunately, nondestructive testing is capable of finding flaws that do not contribute to failure as well as those that do." The casting industry at present is in the throes of trying to determine standards so that castings are not rejected for irrelevant flaws shown up by ultrasonic tests.

R68-13593 ASQC 844; 770

SPACECRAFT RELIABILITY AND QUALIFICATION.

William H. Douglas, Gregory P. McIntosh, and Lemuel S. Menear (NASA, Manned Spacecraft Center, Houston, Tex.).

In: Gemini Midprogram Conference, Proceedings, Houston, Tex., Feb. 23–25, 1965. Conference Sponsored by National Aeronautics and Space Administration, Manned Spacecraft Center. Washington, D. C., NASA, 1966, p. 89–99.
(NASA-SP-121) GPO: $2.75.

Emphasis on high inherent system reliability and low crew hazards characteristics were stressed throughout the Gemini spacecraft reliability and qualification program, with mission success and crew safety design goals established contractually without the classical reliability mean-time-to-failure testing. Design reviews were conducted independently of the designers to insure unbiased evaluations, and a quality control system was rigidly enforced throughout the program planning and actual missions. Closed-loop failure reporting and corrective action required the analysis, cause determination, and corrective action for all failures, malfunctions, or anomalies. The integrated ground test program consisting of development, qualification, and reliability tests was coupled with two unmanned Gemini flights to qualify the spacecraft for manned space flights. M.W.R.

Review: A good perspective is given here on the entire reliability program and qualification testing associated with Gemini. Of course in an overview paper such as this, an aspect which involved much work at a center or in a contractor's organization is often covered by a single sentence or remark. The words here sound the same as those often seen in reliability literature on reliability programs. A difference is that the funding was commensurate with the intent of the words describing the program; that is, actions were taken that are often omitted for lack of funds. Redundancy was used sensibly and the qualification and other testing was most thorough. It is emphasized in the paper that classical MTBF testing was not implemented on Gemini. The use of the word classical here is somewhat questionable. Although this type of testing is often noted in the literature, it has not been used significantly. The over-stress tests which were used on Gemini could just as well be referred to as classical reliability tests. Other papers in these proceedings give an overview of other features of the Gemini program. In a program such as this, reliability objectives are found everywhere and not just in that part which is formally labeled reliability. The success of the Gemini program attests to the value of the reliability features in the work reported in this paper and in others presented at this conference.

R68-13599 ASQC 844; 770

RELIABILITY OF PLATED-THROUGH HOLES IN MULTILAYER BOARDS.

S. A. Di Nuzzo and R. H. Gauger (Hazeltine Corporation, Little Neck, N. Y.).

(Institute of Electrical and Electronic Engineers, International Convention, New York, N. Y., Mar. 21–25, Paper.) IEEE International Convention Record, vol. 14, pt. 9, 1966, p. 106–114. 3 refs.

Accelerated and extended tests for multilayer interconnection boards with plated-through holes show that board performance is limited only by the physical properties of the glass-epoxy board and the current-carrying capacity of the conductors. Fabrication and preparation of test samples are described, and the special test program is noted for measuring the resistance of the conductive paths through the 1454 interconnections on each of the multilayer boards. There was no significant increase in resistance with the interconnection technique used; and the boards were found to withstand extended vibration at 25 g and at least an hour with accelerations as high as 100 g. A 10-day humidity test resulted in no significant deterioration. Seven of the 10 test samples carried a short-term overload current of 25 amperes during destructive high current testing at the end of the accelerated test program. M.W.R.

Review: This is an applications paper which shows the kind of engineering evaluation through which the plated-through holes in multilayer boards were put in order to determine their suitability. The paper itself is short. It discusses the potential failure modes as revealed by earlier experience on single-layer boards. The philosophy of the test was to aggravate severely those same potential failure modes, but without introducing new ones or changing the old ones. The accelerated test consisted of a series of very high "stresses" followed by a step-"stress" to failure by increasing the current. In view of the fact that no failures occurred, the reliability of the plated-through holes is asserted to be very good. The test, and conclusions therefrom, certainly appear reasonable. A consideration of manufacturing variations was explicitly omitted from the test and while they are important in continued use of the technique, the omission does not affect the quality of this paper nor this program.

R68-13603 ASQC 840; 775

INFRARED: A NEW APPROACH TO THERMAL MEASUREMENT FOR RELIABILITY.

Riccardo Vanzetti (Raytheon Co., Wayland, Mass.) and Melvin Mark (Northeastern University, Boston, Mass.).

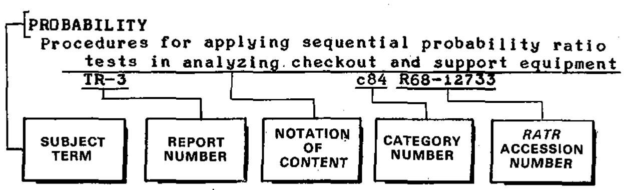
(Institute of Electrical and Electronics Engineers, International Convention, New York, N. Y., Mar. 21–25, 1966, Paper.) IEEE International Convention Record, vol. 14, pt. 9, 1966, p. 137–149.
(A66-24671)

Discussion of examples of applications of infrared techniques to reliability assessment, stress analysis, engineering design evaluation, inspection, testing and trouble-shooting, of electrically energized components, assemblies and systems. In addition to electrical energization from within by power dissipation, thermal energization from without is discussed, along with the possibility of establishing the quality of bonds and joints. The key to forecasting life expectancy of electronics, and the method for achieving a realistic maintenance operation are described. IAA

Review: Apart from an introductory section, this is essentially the same material as found in the paper by the first author in Section B-4 of the volume covered by R67-13234.

SUBJECT INDEX

Typical Subject Index Listing



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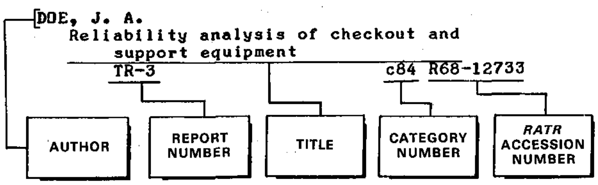
PERSONAL AUTHOR INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS   VOLUME 8   NUMBER 1

Typical Personal Author Index Listing



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Reliability Abstracts and Technical Reviews

FEBRUARY 1968

Volume 8
Number 2

R68-13605—R68-13654

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

ASQC CODES
RATR ACCESSION NUMBER
CORPORATE SOURCE
R68-12733 ASQC 844; 413
TITLE
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
PUBLICATION DATE
AUTHOR
John A. Doe 23 Sep. 1966 27 p refs
CONTRACT OR GRANT
(Contract NAS15-13411)
TAB AND *STAR* ACCESSION NUMBERS
(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65
REPORT NUMBER
SALES AGENCY AND PRICE

RATR ACCESSION NUMBER
R68-12739 ASQC 814
ASQC CODE
TITLE
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
AUTHOR AND AFFILIATION
JOURNAL REFERENCE
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A68-12569)
IAA ACCESSION NUMBER

RATR ACCESSION NUMBER
R68-12765 ASQC 773; 221; 823
ASQC CODES
TITLE
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
AUTHORS AND AFFILIATIONS
CONFERENCE OR SYMPOSIUM REFERENCE
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
AVAILABILITY AND PRICE
IAA ACCESSION NUMBER
(A68-12407)

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A Monthly Publication

of the National Aeronautics and Space Administration

February 1968

80 RELIABILITY

R68-13610 ASQC 800; 830; 880
EFFECTIVE DESIGN FOR INTERPLANETARY EXPLORATION.
Roy B. Carpenter, Jr. (North American Aviation, Inc., Downey, Calif.).
Journal of the Electronics Division, ASQC, Vol. 5 Apr. 1967 p. 2–20. 9 refs.

Mission duration, abort constraint, unknown environmental effects, and reliability assessment are noted as problem areas associated with effective design for interplanetary exploration, with emphasis on manned space flights to Mars and Venus. The reliability problem is defined, and it is concluded that reliability problems related to space missions are overemphasized because a sound system engineering approach can cope with the failures anticipated for missions of long duration. Attention is given to solving the failure problem by using the availability concept; isolating downtime constraints, including crew-induced constraints; optimizing the availability design; and analyzing the maintainability problem. Human factors, logistics, and training requirements are discussed. M.W.R.

Review: A rather general discussion of some of the problems associated with manned interplanetary flights is presented. The range of topics covered is rather wide for a 20-page paper in which half of the space is devoted to tables and figures. Consequently the reader not already intimately familiar with the topics will have difficulty in getting a clear picture of what the author is trying to convey. Table 1 appears to be a sort of bar chart, but no horizontal scale is shown. This table also uses the symbols for the two planets, which few engineers will recognize. The two juxtaposed graphs in Figure 3 are rather confusing (even if the meaning of either graph by itself were quite clear) and takes a while to figure out. The upper graph depicts "failure hazard" as a function of mission duration. "Failure hazard" is defined as "...the cumulated number of expected failures for a given interval of time on a mission." It is impossible to reconcile this definition with a portion of the graph having a negative slope. The comparison itself is poorly described and poorly analyzed in the text because of the apparent incongruity of the assumptions. The distinction between the "availability" and "reliability" approaches is poorly drawn. The maintenance activity appears to be multiple redundancy with cold reserve and a switching delay—which can easily be considered under reliability. The statement "The ordinates R(eliability) and A(vailability) both express the probabilities of mission success" is not correct unless the usual concept of availability is grossly distorted. One part of the author's message which comes through clearly is that for missions of long duration, maintenance is essential. This, however, is just a repetition of the point made by the author in an earlier paper covered by R66-12825. While the other points may have some validity, they are too poorly expressed and too inadequately justified here to be accepted.

R68-13617 ASQC 800
PANEL ON RELIABILITY OF INTEGRATED CIRCUITS.
Charles W. N. Thompson
In: Proceedings of the National Electronics Conference, Volume 23, Chicago, Ill., Oct. 23–25, 1967. Conference Sponsored by the Illinois Institute of Technology, The Institute of Electrical and Electronics Engineers, Region IV, Northwestern University, and the University of Illinois. National Electronics Conference, Inc. 1967 p. 753–755.

Some topics discussed at a National Electronics Conference panel session on the reliability of integrated circuits are presented. Purpose of the panel session was to provide engineers with state-of-the-art data on reliability and maintainability of integrated circuitry (IC). Expectations of aerospace management with respect to microcircuit reliability was discussed, as were the user's viewpoint on IC reliability experiences with microelectronic IC's. M.W.R.

Review: The report of this panel is disappointing in three ways (the last of which is a consequence of printing the Proceedings before the conference): (1) the prepared discussions are reported by abstracts only, (2) three of the seven members have no abstract available, and (3) there is no report of the penetrating questions which were asked nor the responses thereto. It is these penetrating questions and their answers that make a panel discussion worth having in the first place and worth listening to. The prepared discussions only serve to tell everybody what the topic is about. It is often not until the discussion becomes a little heated and some of the panelists drop the company line that any real information comes out. Some of the abstracts say that microcircuit reliability

is great. Some say it is not nearly as high as it is touted to be, and other abstracts are completely innocuous. All in all, it will be worth the while of only very few neophytes to locate this paper and read it.

R68-13635 ASQC 800
GUARANTEED RELIABILITY—SUPPLIER AND CUSTOMER IMPLICATIONS.
E. G. D. Paterson
Industrial Quality Control, ASQC, Vol. 24 Sep. 1967 p. 145–150. 11 refs.

Implications and difficulties of guaranteeing reliability, defined as probability to perform under specified conditions, to the customer are discussed from the point of view of the supplier. And while it is the probability guarantee that is discussed, it is emphasized that it is usually impracticable, if not impossible, to physically prove the validity of a probable value. The true purpose and merit of a measure of reliability is considered to be in its ability to provide a sufficient degree of confidence so that a particular decision can be made. While the nebulous meaning of the word reliability is noted, it is concluded that reliability does prove to be a highly critical component of system performance. M.W.R.

Review: For those who have encountered the term "Guaranteed Reliability" and wondered about its implications, this paper will be worthwhile reading. While much of the content is identified as the author's opinions, those opinions are based on a wealth of pertinent experience. Perhaps the most intriguing question on this topic is that of how "...to physically prove the validity of a probable value." The author considers this and other aspects of the problem and concludes that it is preferable to guarantee performance rather than reliability. This, presumably, is just what the automotive industry is now doing for consumers. Perhaps the defense industries can move in the direction of doing the same thing for the government. Some related papers, mentioned by the author, were covered by R64-11652, R65-12005, and R66-12553.

R68-13652 ASQC 800
INTEGRATED-CIRCUIT RELIABILITY MYTH OR FACT?
Electronic Design, Vol. 15 25 Oct. 1967 p. 26.

Various views relating to integrated circuit reliability are summarized in terms of ideas presented by both users and manufacturers at an IEEE Aerospace and Electronic Systems Group Symposium on microelectronic applications. Both sides agreed that flaws in workmanship were the major cause of IC unreliability; and that poor bonding in the form of overwelds, underwelds, and foreign particles inside sealed headers created the most common assembly problems. The use of headers with plate glass lids was suggested for visual inspection, as was the development of industry-wide life testing methods. M.W.R.

Review: This news item is apparently a summary of a panel discussion on which both users and manufacturers were present. The users, largely or solely from government agencies, complain about the quality and reliability of integrated circuits, saying that they failed to meet the highly touted claims of the manufacturers. One discussant noted that the flaws in workmanship (poor welds and foreign particles) were the same kinds of flaws causing trouble in receiving tubes over a decade ago and that this kind of discussion between the suppliers and the government users was of the same type held about receiving tubes also over a decade ago. Apparently one of the most basic problems is that the government users are small compared to the consumer market and it is difficult to find a way to motivate the manufacturers to produce the high quality product that government users think they want. Nevertheless, equipment made with properly screened integrated circuits can be more reliable than the equipment designed and built some years ago with discrete components. This kind of discussion is very worthwhile not necessarily because it brings buyer and seller closer together, but because it allows many users to find out that their own situation is not unique (as they had thought) but is an industry-wide problem. This panel did not answer the question in the title, but apparently it is both—the reliability in the ads is largely myth, improved reliability over discrete devices (with proper attention to detail) is a fact.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13607 ASQC 810; 770
OPTIMIZING RELIABILITY WITH AN INTEGRATED TEST PROGRAM.
J. E. Carleton and G. N. Holma (General Electric Co., Philadelphia, Pa.).
In: Environmental Evolution, Volume I, 1967 Proceedings of the Annual Technical Meeting, 13th, Washington, D. C., April 10–12, 1967. Sponsored by Institute of Environmental Sciences. Mt. Prospect, Ill. Institute of Environmental Sciences 1967 p. 191–194.

The need for an integrated test program in the development of products is stressed in terms of resulting reliability and optimizing costs. Definitions and purposes of an integrated plan with life, endurance, reliability, and qualification tests are included; and some of the pros and cons of such a program are noted. Test goals and standards are mentioned, along with the documentation of test results. Finally, setting up the integrated test program is considered. M.W.R.

Review: The thesis of this paper is that an integrated test program is a valuable tool that can aid in optimizing reliability, and can at the same time permit reaping a higher return on each dollar invested. The principal advantages and disadvantages of an integrated test program are pointed out. Some typical test definitions and purposes are listed. Test goals, test standards, and measurements are discussed briefly. The basic implementation approach cited is the establishment of an Integrated Test Program Board with responsibility for developing the integrated test plan. The presentation is clear and concise; no references are cited, as the material is apparently drawn from the personal experience of the authors. This paper will be of interest to reliability management personnel who wish to set up or operate similar programs. Test program integration is a matter of degree. The extent of its value is determined by what fraction of available resources it is worthwhile to expend in planning as compared to making the remainder more productive.

R68-13609 ASQC 815; 770
A CONTINUOUS MONITORING TECHNIQUE FOR COMPONENT LIFE TESTS.
Virgil T. Cobb and Lawrence A. Matonak (Bunker-Ramo Corporation, Canoga Park, Calif.).
In: Environmental Evolution, Volume I, 1967 Proceedings of the Annual Technical Meeting, 13th, Washington, D. C., April 10–12, 1967. Sponsored by Institute of Environmental Sciences. Mt. Prospect, Ill. Institute of Environmental Sciences 1967 p. 247–251.

A continuous monitoring technique developed for life testing of relays. is described that can be used, with minor modifications, for testing connectors, resistors, switches, and other components. Relay specification requirements are discussed, and the tester design is described. This includes the relay operation and contact monitoring circuits, timing circuits and sequencing, and the computer inputs and outputs. The life tester block diagram is shown. M.W.R.

Review: A description is given of a life test program conducted on relays to satisfy specific test requirements. A feature of the program is the use of a digital computer to obtain a continuous record. The discussion is clear and concise; no references are cited. The paper will be of interest to reliability engineers as an example of one approach to the life testing of components. As the authors have indicated, the technique could be used for testing such components as connectors, switches, resistors, etc.

R68-13616 ASQC 815
ENSURING RELIABILITY OF SOLDERED CONNECTIONS.
The Magazine of Standards, Vol. 38 Oct. 1967 p. 290–291.

The *USA Standard for Criteria for Inspection for Highly Reliable Soldered Connections in Electronic and Electrical Applications,* C99.1–1966, is reviewed; and several diagrams relating to soldered connections are included. These depict the transmission of stress to a mechanical connection, stress relief for component pigtail leads, pierced terminal connections, connector-free floating terminals, hollow terminal connections, and cup-type terminals. It is noted that the standard deals only with inspection criteria for soldered connections. M.W.R.

Review: The referenced standard is undoubtedly a boon to high-reliability efforts, but the criteria for goodness of a soldered joint do change. For example, many years ago, the joint was required to be mechanically solid before it was soldered; now most of the joints are not. One reliability reason for not having them mechanically solid is that if someone misses soldering them, a vibration test can show up the defect; whereas if the joint were mechanically solid it would not show up perhaps until it corroded. A picture in the text shows the "proper" way to mount a resistor or similar component. Apparently the way it has been done for many years is wrong, but the method shown as acceptable would surely flunk a good vibration test because of the slack in the lead and the component's not being fastened to the board. This shows that the standards must still be applied to knowledgeable people who understand what the picture is intended to show and what it is not intended to show. This paper does not analyze the standard completely; it just talks about it and gives some of its purposes. Those interested will, of course, buy copies of the standard.

R68-13627 ASQC 810
FORUM ON RELAYS.
Bill Segallis, ed.
Electronic Products, Vol. 10 Oct. 1967 p. 50, 51, 53, 54, 56, 58, 60, 62, 64, 66, 70, 72, 74, 76, 80, 82, 84, 86.

Solid state versus electromechanical relays are discussed, and the electromechanical devices are considered to exhibit remarkable ability to adapt to the changing needs of electronic technology. Advantages cited for relays in general are cheaper and less complex circuitry, better isolation, greater resistance to transients and less tendency to generate transients, and fewer grounding problems. In addition, relays have higher dielectric strength and insulation resistance, can handle more power with less loss from constant or ON resistance, can be kept in ON position for long periods of time, dissipate heat more readily, and have longer shelf life. The search for smaller relays is discussed, and the TO-5 relay is considered in this light. The pros and cons of bifilar winding are discussed as another new aspect in relay development. Reliability is discussed in terms of military specifications and vendor requirements. Other subjects considered are cleanliness, headers, user–manufacturer liaison. Participants in roundtable discussions held in New York, Chicago, and Los Angeles contributed to this forum on relays. M.W.R.

Review: This summary of the Forum on Relays illustrates well why there are reliability problems with any component. Many of the points of discussion boil down to the accusation "Why don't you do it right?" and to "I don't trust you, so I will do it myself." While the relay manufacturers suggest that the best way to handle the problem is to turn it over to them at an early stage, it is obvious that many engineers have had sad results from this procedure. Vendors do need to be consulted, designers do need to be more discriminating and knowledgeable, vendors do put out some poor quality material, designers do ask for too much. Most of the material deals with state-of-the-art relays. Presumably high reliability is available in many applications if one is willing to pay the size and weight penalties. The article does not really answer any questions; it probably was not intended to. But it does give a great deal of worthwhile perspective on the problem of reliable application of reliable relays (as well as buyer–seller problems in general). In order for both the designer and the manufacturer to be sure that the relay is the proper choice and is properly applied, each will need to duplicate some of the analysis to make sure that the other has done it properly. This duplication or redundancy is probably unavoidable for high reliability.

R68-13632 ASQC 812
INDUSTRIAL QUALITY CONTROL, ASQC, VOLUME 23, NUMBER 12.
June 1967 88 p. 82 refs.

Education and training at the high school and higher levels are discussed in relation to quality control and reliability in a series of articles by representatives of the educational, research, and engineering communities. The National Science Foundation efforts in quality control, reliability, and statistics training is treated in one article; and the statistical training center of the Turkish State Institute of Statistics is also considered. The role of technical information services in engineering training, programmed instruction and other teaching aids, and the future of reliability education programs are discussed. M.W.R.

Review: This entire issue of *Industrial Quality Control* is devoted to education and training, and many of the articles are related to reliability. The articles generally tell what kind of educational aids are available and tend to evaluate them rather than to describe them in detail. For any individual engineer the programs described can have very widely different applicabilities. For example, his own ASQC sections or divisions may have virtually no educational activities from which he can benefit. Virtually all of the articles describe company-sponsored or company-subsidized activities such as inhouse training programs or external seminars and symposia. One article on technical information services is written directly for the individual engineer. The experienced engineer will be well aware of most of its contents, but recent graduates may find valuable information here. It is unlikely that any particular engineer will find anything of extreme value in any of the articles, but a quick browsing through them may pay for itself in terms of awareness, not only of what is going on, but also of what is not going on.

R68-13633 ASQC 810
MANAGERIAL ASPECTS OF RELIABILITY—A REVISED VERSION OF DOCUMENT 56 [SECRETARIAT] 10.

Industrial Quality Control, ASQC, Vol. 24 Jul. 1967 p. 34–36.

Basic concepts, reliability program scope, and engineering reliability activities are considered in a revision of a tutorial document on the reliability of electronic components and equipment prepared by a committee of the International Electrotechnical Commission. Research and training, design reliability establishment and assurance, manufacturing reliability establishment and assurance, and user reliability support are discussed from a management viewpoint. M.W.R.

Review: This document presents the recommendations of the IEC TC 56 Committee on how a reliability program should be organized and managed. Because of its broadly applicable content, it should be read widely by industrial management. It has been described as a basic tutorial document on reliability management, and is well organized and clearly and concisely presented. The term "inherent reliability" is used throughout the document, apparently with reference to something which is established by design, and can only be degraded by subsequent activities. It is unfortunate, especially in a document of this kind, that no precise definition of this concept of "inherent reliability" is given. Despite its frequent occurrence in the reliability literature, this term is not well defined and can be misleading. A term such as "reference reliability" might convey the meaning more clearly—still accompanied by a precise definition of what is meant. Thus, while this document is somewhat less tutorial than may have been anticipated, it will be worthwhile reading for those concerned with reliability program management and reliability engineering activities.

R68-13653 ASQC 814; 612; 770

Society of Automotive Engineers, Inc., New York.

SIMULATION OF FIELD LOADING IN FATIGUE TESTING

John C. Conover (Ford Motor Co.), Henry R. Jaeckel (Ford Motor Co.), and Wayne J. Kippola (Ford Motor Co.) 14 Jan. 1966 20 p refs Presented at Automotive Eng. Conf., Detroit, 10–14 Jan. 1966

(SAE Paper-660102; N68-80414)

A technique for simulating field loading in laboratory fatigue testing yields good correlation with field life, significantly reduces testing time, and permits quick checking of modifications. The technique uses simple load control programs that are usable by most fatigue testing machines and servohydraulic test equipment. The simulation technique is described following a review of fatigue under random loading. Loading under service conditions is measured, and this measured loading is simulated on a laboratory specimen. The overall technique combines known simulation methods with test acceleration using a mixed cycle S–N curve and the simulation of multiple modes of loading. The technique is applied to automotive parts, and correlations between actual road and laboratory tests permit accurate estimation of fatigue performance of components and subsystems in terms of miles of equipment operation. M.W.R.

Review: This paper does an excellent job of describing techniques for the acceleration of simulated road tests based on actual field data. Its greatest contribution is a method of accelerating tests for single and multiple modes of loading by the use of uniform load intensification of the test load spectrum, which spectrum has been previously developed from road load histograms. An intensity factor is established for reducing the accelerated data to the proper reference. The concept of intensifying the spectrum (mixed load) *fatigue tests that simulate field loading is certainly one that* deserves attention. The technique has been verified by tests and appears to be a break-through in the problem of finding a reliable method for reducing the time required to obtain fatigue results and yet have them representative of component life under random loading. The paper illustrates well the organization of a cumulative-damage fatigue-program from actual roadload data. It is highly recommended for anyone who is studying the effects of random fatigue loading.

R68-13654 ASQC 810

Library of Congress, Washington, D. C. Aerospace Technology Div.

SOVIET COMPUTER RELIABILITY

Stuart G. Hibben *In its* Foreign Sci. Bull., Vol. 2, No. 11 (See N68-80415) Nov. 1966 p 1–13 refs

(N68-80416)

Failure histories and overall reliability are discussed for the Ural-2, M-20, and Dnepr computers; and the lack of trained operating and maintenance personnel is considered the most urgent problem related to improving reliability of Soviet computers. The low quality of magnetic tape is noted, and mention is made of the short periods of failure-free operation reported for Soviet computers. For the Dnepr computer, it is noted that 22.1% of the failures occur in one communications unit and 10.8% in another, 19.7% in the core memory, and 15.4% in the input/output unit. Breakdown of time expenditure on a contemporary Soviet computer, not specifically identified, is given as 52.8% useful machine operating time, 18.8% preventive maintenance time, 7.7% dead time from lack of users, 5.6% fault repair time other than preventive maintenance, 5.0% dead time from lack of maintenance personnel, 4.1% from primary power failures, 2.4% for repair of faulty solder joints, 2.0% machine demonstration time, 0.4% lost from overheating, and 0.53% attributed to unknown failures. M.W.R.

Review: This is a good article, and in giving a perspective on the reliability of Russian computers it helps us see where the same things are giving us trouble in this country. Certainly there is little evidence that much smugness on our part is justified. While our best may be much better than the Russians', much of our equipment has its faults. The lack of trained people for maintenance is apparently a peculiarity of the human race rather than of a particular country. Even though the article has no direct bearing on the reliability of aerospace equipment in this country, reading it is valuable because of the outlook it affords on reliability problems in general. (An article on this subject by the same author, apparently a condensation of this report, appears in *Datamation*, vol. 13, Aug 67, p. 22–25; see R67-13535.)

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13613 ASQC 824; 433

CONFIDENCE INTERVALS FOR SYSTEM RELIABILITY FROM COMPONENT TESTING USING CONVERSE HYPERGEOMETRIC PROBABILITY DISTRIBUTIONS.

Audrey A. Keefe and Harold T. Ohara (Naval Ammunition Depot, Quality Ammunition Depot, Lualualei, Hawaii).

Journal of the Electronics Division, ASQC, Vol. 5 Apr. 1967 p. 21–32. 12 refs.

A Bayesian approach that uses converse hypergeometric probability distributions is followed in determining confidence levels for system reliability from component testing data. It is assumed that all population configurations are equally likely prior to sampling, and the method considered combines results of component or subsystem testing in a given system to obtain confidence levels for

true system reliability based on distributions for each of the system components. Both hypergeometric and converse hypergeometric probability distributions are discussed, as is the Boolean algebra of simple networks. Probability occurrence distributions of reliability for each component type are tabulated, as are the occurrence probabilities for system reliabilities. M.W.R.

Review: A Bayesian procedure is presented for obtaining a confidence interval for system reliability from the results of component testing. It is assumed that the population of components of each type is finite. Consequently, the hypergeometric function distribution is applicable. A uniform prior distribution is assumed for the number of defectives in the population. This is a weak assumption and it may not always be a reasonable description of one's prior knowledge. As a consequence of this weak a priori assumption it is expected that the procedure will be robust for moderate sample sizes, that is, the a posteriori distribution will be essentially independent of a priori assumptions. The example given in the paper to demonstrate the confidence interval estimate procedure is a rather simple one and it points out the degree of tediousness in the computational procedure which would result from a similar analysis of complex systems. The second and third equations at the top of page 23 may appear rather awkward at first reading and it is important to realize that these particular forms result because of the equal prior probabilities, $P(M_i)$. The assumptions for the method are clearly stated. The paper should be of interest to those wishing to apply Bayesian techniques.

R68-13615 ASQC 824; 844

FATIGUE FAILURE UNDER COMPLEX STRESS HISTORIES.

T. D. Scharton and S. H. Crandall (Massachusetts Institute of Technology, Dept. of Mechanical Engineering, Cambridge, Mass.).
(American Society of Mechanical Engineers, Metal/Production Engineering Conference, Berkeley, Calif., Jun. 9–11, 1965.) ASME, Transactions, Series D—Journal of Basic Engineering, Vol. 88 Mar. 1966 p. 247–250; Discussion, J.Schijve (National Lucht- en Ruimtevaartlaboratorium, Amsterdam, Netherlands), p. 250, 251; Authors' Closure, p. 251. 21 refs.
(Contracts AF 49(638)-564; AF 49(638)-1314; Grant AF-AFOSR-282-63)
(ASME Paper-65-MET-3; A65-28649; A66-24555)

Derivation of an expression for predicting fatigue failure of a structure subjected to sinusoidal stress cycles of different amplitudes and mean values is based on a steady-state model of fatigue crack growth. For two cases, predicting inservice fatigue and predicting crack growth in a laboratory test, the derived expression is substantially equivalent to the classical linear damage rule. The crack-growth derivation extends the classical linear damage concept of the problem of predicting the remaining fatigue life of a partially damaged structure. Author (IAA)

Review: The authors derive an interesting mathematical expression for predicting fatigue crack growth under complex stress histories, and they show how their expression reduces to the simplicity of the Palmgren-Miner linear damage rule for two special cases. As pointed out in an appended written discussion by another authority in the field, the most serious weakness in this approach is probably the absence of consideration of the interaction of various stress cycles with the residual stresses at the crack tip. The mathematics was checked and appears to be correct. The article is readable and a useful engineering reference.

R68-13624 ASQC 824; 433

BAYESIAN ESTIMATES OF THE RELIABILITY FUNCTION.

M. S. Holla (Defence Science Laboratory, Delhi, India).
Australian Journal of Statistics, Vol. 8 1966 p. 32–35. 13 refs.

A Bayesian approach is taken to the classical problem of estimating the reliability function when the underlying life distribution is specified by a gamma density and the prior information is represented by either a natural conjugate or a quasi density. Equations are evolved for the reliability estimation under both the natural conjugate prior and the so-called quasi prior; and estimates of reliability and variance are presented for a problem in which failure times are available for a given system. M.W.R.

Review: This short note presents the rather straightforward calculations necessary to obtain a Bayesian estimate of the reliability function when the underlying life distribution is of Gamma type. Two possible prior distributions are considered, the Gamma distribution (natural conjugate) and a quasi-density which is equal to a known power of the parameter. The resulting estimates are expressed in terms of certain higher transcendental functions, viz., incomplete Beta and hypergeometric functions; thus their use is somewhat limited by availability of tables, etc.

R68-13631 ASQC 824

A SIMPLE ESTIMATION OF FAILURE RATE.

J. Temler
Microelectronics and Reliability, Vol. 6 Aug. 1967 p. 239–240.

A formula is given for estimating the upper limit of failure rate at the 50% confidence level, and some values are tabulated for several numbers of failures up to 15. The equation considers the number of test items, length of testing, number of failures, and elapsed time; and a special indication for elapsed time for the case with replacement or repair. M.W.R.

Review: This paper gives a simple linear approximation to χ^2_{2n+2} for 50% probability. From the author's comparison it appears to be accurate within ±.01: the approximation is low for $n=0$, almost correct for $n=1$, and approximately .01 too high for $1<n<15$. The author's comparison table goes up to only 15, but the approximation compares favorably with an asymptotic formula of $n+2/3+1/13(n+1)$. Approximations such as this are fun to figure out and are convenient to use if many calculations must be done at once. For those with just occasional need for them, it is probably easier to look up the numbers in a set of tables than it is to try to find the formula.

R68-13634 ASQC 823

A SHORTCUT FOR DETERMINING SEMICONDUCTOR FAILURE RATES FROM MIL-HDBK 217A.

J. T. Henderson (Gulton Industries, Inc., Data Systems Div., Albuquerque, N. Mex.).
Industrial Quality Control, ASQC, Vol. 24 Oct. 1967 p. 207–208.

Semiconductor failure rates are determined by a shortcut method that is derived from three basic equations, referenced in MIL-HDBK 217A, that permit calculations from a stress analysis worksheet that is power-dissipation oriented. Time savings are realized by eliminating reference to the applicable device data sheet as well as by less arithmetic processing. The MIL-HDBK 217A method of calculating normalized junction temperature is detailed. It is noted that the proposed short cut will not apply to case numbered devices with unknown case temperatures. M.W.R.

Review: This is a short paper that can make work easier for reliability engineers who must make the indicated calculations. It is a good example of algebraic manipulations without approximations so that the desired result is calculated more easily than otherwise would have been possible. Appropriate cautions are inserted to warn against cases where the original and consequently the final equations are not valid. For those who are not involved in making this kind of calculation the article will be of no interest.

R68-13637 ASQC 824; 844
SYSTEM RELIABILITY SYNTHESIZED FROM COMPONENT RELIABILITIES UNDER NON-INDEPENDENCE OF STRESSES.
J. R. Duffett (TRW Systems, Cocoa Beach, Fla.).
The Logistics Review, Vol. 3 May/Jun. 1967 p. 15–32.

Reliability determinations are made for parallel, series, parallel-series, and series-parallel systems by using component reliabilities. It is assumed that component strengths, regardless of the flight in which they are incorporated, are independently selected from a fixed rectangular probability distribution; and that the common stress applied to all components within the same flight is also independently selected. Failure criteria are given for each type of system; and the explicit relation and recurrence relation are evolved for each system. Some reliabilities are tabulated for various values of component reliability. M.W.R.

Review: Relatively little discussion exists in the literature concerning the topic area of this paper. Some tables are presented which apparently do not appear anywhere else. The tables were spot-checked by deriving several of the equations and by solving several simple problems using both the given equations and another approach involving expected value notions. These checks indicated agreement with the given equations. Assumptions on which the tables are based are given. A caution concerning the formulas given in the tables is that the formulas cannot be "pieced" together where the stress is common to these "pieces." The paper is mute on this point. For cases where formulas given in the tables do not apply, a separate derivation would be needed. Little is given in the paper concerning the derivation of the formulas presented in the tables. Also, the interest with this type of problem extends beyond the assumptions used in this paper, e.g., to non-rectangular distributions, components with different strengths, or components whose reliability is a known function of stress. A derivation of one of the formulas or some discussion of derivation would have been desirable. This would have helped to present the problem more clearly; it would have assisted in extending the approach to other situations and in avoiding the potential mistake of piecing together given formulas.

R68-13638 ASQC 822; 424
A MULTIVARIATE EXPONENTIAL DISTRIBUTION.
Albert W. Marshall (Boeing Scientific Research Laboratories, Seattle, Wash.) and Ingram Olkin (Stanford University, Calif.).
Journal of the American Statistical Association, Vol. 62 Mar. 1967 p. 30–44. 10 refs.
(Grant NSF GP-3837)

Multivariate exponential distribution derivations are presented, along with indications for their applicability. While two of the derivations are based on shock models and a third assumes that residual life is independent of age, all of the derivations lead to the same distribution. Both a fatal and nonfatal shock model are discussed for the derivation of a bivariate exponential distribution; and the residual life independent of age model begins with a univariate exponential distribution. Distribution function, moment generating function, distributions obtained by a change in variables, and representation in terms of independent random variables are considered. Minima of exponential random variables are discussed, and a comparison of the bivariate exponential is compared with the case of independence. The multivariate distributions are then derived and their properties discussed; and it is shown that a multivariate Weibull distribution is obtained through a change of variables. M.W.R.

Review: This paper was covered by R67-13096

R68-13639 ASQC 823
LIFE-TESTING RESULTS BASED ON A FEW HETEROGENEOUS LOGNORMAL OBSERVATIONS.
A. J. McCulloch (Lockheed-California Co., Burbank) and John E. Walsh (System Development Corp., Santa Monica, Calif.).
Journal of the American Statistical Association, Vol. 62 Mar. 1967 p. 45–47.

Some similar items are to be independently life-tested under "typical" conditions. The interest is in predetermining a length of time such that the probability is at least a specified amount that an item will survive this long. A random lower bound for this time is to be evaluated from preliminary independent life-tests on a few items, combined with supplementary information. The time to failure for an item is assumed to have a lognormal distribution. The testing conditions are the same for the items to be life-tested later. However, the few items tested first might be subjected to different conditions. A consensus of these conditions furnishes the "typical" conditions. The few observations are used to allow for mean effects, and an upper bound (perhaps rough) for the variation effects is provided by the supplementary information. The resulting bounds can have strong advantages over use of a *t*-statistic when only two or three items are considered initially. Author

Review: This is a rewritten version of the report covered by R65-12245, and contains essentially the same material as the earlier publication.

R68-13640 ASQC 824; 433
BAYESIAN APPROACH TO LIFE TESTING AND RELIABILITY ESTIMATION.
Samir Kumar Bhattacharya (Defence Science Laboratory, Delhi, India).
Journal of the American Statistical Association, Vol. 62 Mar. 1967 p. 48–62. 19 refs.

A Bayesian analysis of the exponential model was developed based on life tests that are terminated at preassigned time points or after preassigned time points or after preassigned number of failures. For the prior distribution of the parameter involved, uniform inverted gamma and exponential densities were examined. The estimation of the reliability function was carried out by using Bayesian methods and the case of 'attribute testing' was considered briefly. The role of prior quasi-densities when a life tester has no prior information is illustrated, and it is observed that the reliability estimate for a diffuse prior which is uniform over the entire positive real line closely resembles the classical MVU estimate obtained by Pugh. The Bayes estimate of the exponential parameter for a prior quasi-density of the form $1/\Theta^2$ coincides with the classical MVU estimate of Epstein and Sobel; and that in a wide class of prior densities that are proper or improper, $1/\Theta^2$ is the only prior which leads to the MVU estimate. Author

Review: This is a mathematical paper treating the Bayesian approach to life testing and reliability estimation. It has one feature which is not found in the usual papers on Bayesian techniques. The author uses the notion of prior quasi-density functions which differ from the usual prior density in that the integral of this density over the range of values of the parameter does not have to be unity. For example, the family of functions given by $g(\Theta) = 1/\Theta^a$ $(0 < \Theta < \infty)$ are prior quasi-densities. The introduction of these more general densities is important because the author shows that the form $1/\Theta^2$ yields the same estimate of the exponential parameter as that of Epstein and Sobel. The paper provides several formulas for the a posteriori estimates of reliability for three forms of the prior density function, the inverted Gamma density, exponential density, and one other general form (constant x $1/\Theta^a$) defined on a finite interval. This paper contains many results which should be

of value to anyone involved in reliability estimation problems and interested in Bayesian methods. The mathematical results are formidable; however, the paper is well-written and the reading is not so difficult.

R68-13641 ASQC 824

ESTIMATION OF THE PROBABILITY OF ZERO FAILURES IN BINOMIAL TRIALS.

Herbert C. Rutemiller (California State College, Fullerton).

Journal of the American Statistical Association, Vol. 62 Mar. 1967 p. 272–277. 2 refs.

The maximum likelihood estimator and minimum variance unbiased estimator of the probability of zero failures in *m* binomial trials were compared on the basis of expected squared estimation error. The choice of estimator proved to be a function of the region of parameter space. However, the m. 1. e. was preferred throughout the regions likely to be encountered in practice (where the probability of zero failures exceeded 0.5). Author

Review: This is a mathematical paper addressed to the comparison of two statistical estimators, rather than to their practical application. Consequently the results will be of interest to the statistician concerned with reliability estimation procedures rather than to the reliability engineer. These estimators do have practical applicability to series systems in which the components are classified as good or bad. Not all of the mathematical details were checked, but the work appears to be of good quality.

R68-13642 ASQC 822; 424; 824

A BIVARIATE WARNING-TIME/FAILURE-TIME DISTRIBUTION.

George A. Mihram (Oklahoma State Univ., Stillwater), and Robert A. Hultquist

Journal of the American Statistical Association, Vol. 62 Jun. 1967 p. 589–599. 12 refs.

A bivariate density function is defined by introducing a failure warning-time variable whose range is equal to the failure time of the component being tested. The marginal distribution of the failure time is taken to be Stacy's generalized gamma distribution, and the determining conditional distribution of the warning-time variable is assumed to be a normalized beta distribution. Parameter estimation is indicated for the resulting five-parameter bivariate density. Details are presented for the beta and gamma distribution and for point estimation for the bivariate density; and minimum variance bounds and sufficiency are discussed. Some special cases of the beta/Stacy distributions are presented that are based on restricting the parameter space associated with the density; and measures are provided of dispersion of the scale parameter estimates calculated from the sample of warning times. M.W.R.

Review: This is a mathematical paper concerned with the properties of, and parameter estimation for, a five-parameter bivariate density function. Not all of the mathematical details were checked, but the material appears to be of good quality. The work is adequately referenced to indicate its orientation relative to other published research. While this paper is not concerned with applications, the authors do mention the potential usefulness of the concept of a warning-time variable as a means of reducing testing time. For example, in accelerated testing, the possibility exists of defining the observed *stressed* failure-time as a warning-time variable. This idea may well be worth further attention.

R68-13643 ASQC 821; 837

Joint Publications Research Service, Washington, D. C.

UNCORRELATED METHOD OF RELIABILITY CALCULATION OF AUTOMATIC SYSTEMS

A. A. Bessonov *In its* Izv. Vuzov: Instr. Bldg., Vol. 9, No. 2 23 Feb. 1967 p 141–146 refs (See N67-28101 15-14) (N67-28129)

Consideration is given to the possibilities of forecasting reliability of automatic systems by evaluating the correspondence of their properties to the generalized function. This makes it possible to eliminate unwieldy calculations and ignore correlation between random variables. Author

Review: This translation from the Russian is difficult to read and nearly impossible to make sense of. Apparently what the author is saying is that an absolute worst-case method of analysis for a circuit is often satisfactory and that in this analysis any correlations should be neglected. Presumably he means any correlations where the probability is not practically one. Actually if it were quite close to one it should be considered. Since these kinds of analysis are well discussed in the American literature, there is no need for anyone trying to read this translation.

R68-13644 ASQC 824; 830; 844

SAAB Aircraft Co., Linkoping (Sweden).

A METHOD FOR PRELIMINARY ESTIMATION OF FATIGUE STRENGTH IN AIRCRAFT PRIMARY STRUCTURES

Sven Erik Larsson May 1965 48 p refs

(SAAB-TN-57; N67-11754) CFSTI: HC$3.00/MF$0.65

A systematic fatigue strength calculation, based on a number of load spectra and on linear cumulative damage theory, has been made for 12 different skin elements, most of them riveted joints. Information relating to fatigue strength, obtained in constant amplitude tests, for these structural elements was taken from various sources. Author

Review: The author has skillfully taken available load spectrum data for several kinds of aircraft and has devised an interesting approach for using such data in combination with cumulative fatigue theory to estimate the fatigue strength of various aircraft joints. This approach furnishes the designer with a fatigue safety factor which is based on actual flight data. However, when considered in light of variation and scatter in actual load histories, quality of joint, accuracy of cumulative damage theory, scatter in material strength, and accuracy of the Goodman diagram for use in predicting life at various mean loads, the accuracy of a calculated safety factor is subject to question. The report seems to be a noble attempt to obtain a solution from the extrapolation of a limited amount of data using analytical methods of questionable accuracy. At any rate, the paper is interesting since it does present another approach to the complicated problem of designing for fatigue in aircraft.

R68-13649 ASQC 824; 433

RAND Corp., Santa Monica, Calif.

STATISTICAL ESTIMATION BY THE EMPIRICAL BAYES METHODS: SOME EXTENSIONS AND LOGISTICAL APPLICATIONS

S. James Press Jun. 1965 43 p refs

(Contract AF 49(638)-700; Proj. RAND)

(RM-4442-PR; AD-617606; N65-32696)

Explicit estimators are presented for the univariate and multivariate exponential family of distributions, for distributions with nuisance parameters, and for the distribution of a family of random variables. Examples are given to show how these data apply to logistical problems, particularly to the estimation of Poisson-process generated demand parameters and repair-time distribution parameters. An empirical Bayesian approach is taken for which there is no need to assume any particular form for the *a priori* distribution of the parameter. The procedure can be used to improve methods of estimating statistical decision parameters in such logistical problems as reliability, maintenance, and supply. M.W.R.

Review: This report is of potential value to applied reliability workers in that it gives an introduction to and some numerical examples of the "empirical Bayes method" of estimation. However, there are some difficulties in the exposition and it is questioned whether or not a beginner could understand the method from this report alone. The references are very helpful, though. Some specific criticisms of the report follow. Firstly, since empirical Bayes estimates (e.B.e.'s) and maximum likelihood estimates (m.l.e.'s) are based on *different models* they are not really comparable, especially in the extreme case where the a priori distribution is degenerate. Clearly, in this case, no one would use the usual m.l.e. (In this case one might consider the parameter space as containing a single point and then the m.l.e. and e.B.e would coincide.) The results on p. 14 concerning the empirical probabilities converging to the true probabilities are not true unless the intervals Δt_i are all equal. Similarly, the limiting results at the bottom of p. 17 will not be true unless $\hat{p}_n(x)$ converges uniformly in x. Similar criticisms may be made concerning the remainder of the report.

R68-13650 ASQC 824
Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.
SUFFICIENT CONDITIONS FOR ASSOCIATION OF BINARY VARIABLES
D. W. Walkup Dec. 1966 22 p refs *Its* Mathematical Note No. 423
DI-82-0444; AD-648147; N67-26883) CFSTI: HC $3.00/MF $0.65

In connection with studies of reliability of coherent binary systems, it has been suggested that a set of binary random variables be called associated if all pairs of binary nondecreasing functions of these variables have nonnegative covariance. In this note it is shown that there exists a unique smallest set A of pairs of binary nondecreasing functions on the variables such that nonnegative covariance for the pairs in A is necessary and sufficient conditions for association of the variables. This set A is characterized and it is shown that its size increases rapidly with the number of variables. It is also shown that for four or more variables there exist pairs in A corresponding to coherent systems with no nontrivial modules, thus suggesting it is impossible to find an equivalent definition of association of binary random variables which makes material use of partitioning of the variables. Author

Review: The results and proofs in this report are quite theoretical and will probably not be of interest to the applied reliability worker. However, the work is certainly of theoretical interest in the study of the reliability of certain systems and may, of course, lead to fruitful practical ideas in the end. In particular, the report contains a rather complete set of references to the earlier work in this area. A related paper was covered by R67-12969; a more closely related paper is [1].

Reference: [1] J. D. Esary, Frank Proschan, and D. W. Walkup, "A multivariate notion of association, with a reliability application," Mathematical Note No. 484, Mathematics Research Laboratory, Boeing Scientific Research Laboratories, Oct. 66 (AD-644 094).

R68-13651 ASQC 824; 433
Research Analysis Corp., McLean, Va.
BAYESIAN ANALYSIS OF THE WEIBULL PROCESS WITH UNKNOWN SCALE PARAMETER
Richard M. Soland Aug. 1966 24 p refs
(Contract DA-44-188-ARO-1)
(RAC-TP-215; AD-643816; N67-19824) CFSTI: HC $3.00/MF $0.65

The Weibull process with unknown scale parameter is taken as a model for Bayesian decision making. The family of natural conjugate prior distributions for the scale parameter is exhibited and used in prior and posterior analysis. Preposterior analysis and several sampling schemes are then discussed. Preposterior analysis is given for a two-action problem with utility linear in the unknown mean of the Weibull process, in which the sampling scheme yields the first r failures in a life test of n items. An example is included. Author

Review: A Bayesian estimation procedure for the scale parameter in a Weibull distribution with known shape parameter is presented in this report. The discussion should be readable by someone with an introductory knowledge of Bayesian statistics although some of the notation makes the exposition rather difficult to follow. The notation used in introducing the natural conjugate prior distribution is especially bad and indeed confusing. Once one gets by this point things proceed fairly smoothly. Several different sampling plans are considered and a concrete numerical example closes the report.

83 DESIGN

R68-13623 ASQC 830; 844
AN APPLICATION OF AUTOMATIC FAILURE DETECTION AND CORRECTION TO A SPACECRAFT COMMAND DETECTOR.
R. Obryant (Texas Instruments, Inc., Dallas, Tex.).
In: NTC/66; Proceedings of the 1966 National Telemetering Conference, Boston, Mass., May 10–12, 1966. Conference Sponsored by the Institute of Electrical and Electronics Engineers, The Instrument Society of America, and The American Institute of Aeronautics and Astronautics. Bedford, Mass. Raytheon Co. 1966 p. 124–126. 13 refs.
(A66-35679)

Discussion of the principles of designing self-checking systems for the detection, location, and correction of failures in unmanned spacecraft. Their application to a spacecraft command detector design is considered. This detector detects binary command data from a frequency-shift-keyed subcarrier. Each of the frequencies has its own detection channel within the command detector and a decision is made on the received bit by a comparison of these channels. The addition of only two circuits creates three paths of information flow through the system. Self-checking logic is implemented which selects the appropriate path and connects it to the output. The logic is capable of correcting a single failure anywhere in the system, including the checking logic giving the functional equivalent of a redundant system with only a 1.65 times increase in components compared to 2.5 times for full redundancy. The appropriate use of integrated networks reduces this to only 1.1 times. IAA

Review: This paper can be of value to the circuit designer since it is a brief description of the application of self-checking and correction in an electronic circuit. It introduces the subject to those who are not yet familiar with it, but of course does not go into the many details. The paper gives references which show that self-checking is more efficient than some other methods for increasing reliability. This result obviously depends on the criterion for efficiency, which in this case is apparently some sort of parts count, and the result is true only in the framework (picture or model) which was analyzed. In the example given in the text, it is apparently presumed that some of the failures are not the kinds which will

short out too many other things. For example, a short on the input to the #2 shaper for data could conceivably cause failures of a shorting nature in the differential detector which would in turn cause both of the other detectors to fail. Even though the hypothesized condition may be remote, it does serve to illustrate that certain kinds of failures are being analyzed and not others.

84 METHODS OF RELIABILITY ANALYSIS

R68-13605 ASQC 844; 775
IMPROVED DECONTAMINATION RELIABILITY... THROUGH RADIOGRAPHIC ANALYSIS.
Victor B. Kavits (Ogden Technology Laboratories, Inc., Deer Park, N. Y.).
Environmental Quarterly, Vol. 13 June 1967 p. 28–29.

Radiographic analysis is considered as a method for improving decontamination reliability of permanently assembled units. To develop a radiographic technique, a mockup was constructed of a test panel equivalent to the cold plate for the lunar module; and test radiographs were prepared to determine optimum cold plate density. The specimen was then salted, and radiographs were made through sealed nylon; and results are given for measurable particles, equipment and materials, and radiographic parameters developed. Additional investigations were made to determine the feasibility of using radiographic techniques on other hard to clean components. Radiographic particle analysis is recommended for relatively smooth or uniformly machine-surfaced components; as well as for determining the presence of foreign embedments in basic material. M.W.R.

Review: A short, straightforward description is given of a non-destructive method for inspecting assembled units for the presence of contaminant particulate matter. Information is given on the measurable size of particles, necessary equipment and materials, and radiographic parameters pertaining to the X-ray process. Some limitations of the radiographic analysis technique are pointed out. This paper will be of value to those who wish to look into the potential of this technique for reducing contamination failures and thus enhancing reliability and mission success.

R68-13606 ASQC 844
Department of Supply, Melbourne (Australia).
SENSE AND NONSENSE IN ELECTRONIC RELIABILITY ENGINEERING
J. H. Sharpe [1967] 8 p refs *Presented at the 1967 Radio* and Electron. Eng. Conv., Sydney, 22 May 1967

High stress testing and failure mechanism determination are considered valuable tools for improving reliability of electronic equipment in an overview of tools available to the reliability engineer. Various aspects of the 1957 AGREE (U.S. Advisory Group on Reliability of Electronic Equipment) are mentioned, and pitfalls that threaten the reliability engineer are noted. Wear-out of electronic parts and the use of the Arrhenius equation are discussed. M.W.R.

Review: The thesis of this paper, in keeping with its title, is that various procedures for the measurement and demonstration of reliability in quantitative terms outlined in the AGREE report lead to a considerable amount of nonsense, whereas there is a lot of sense in high-stress testing. The author's presentation, so far as it goes, does make sense. High-stress testing and studies of mechanisms of failure do offer hope for progress in quantitative work in reliability. Many of the comments in the text about the Arrhenius relation are matters of important controversy, not statements of fact. On the implementation of these ideas, however, the paper offers very little. For those who are interested in following up on these ideas, the references cited by the author are among those which will be helpful.

R68-13608 ASQC 844; 775
THE DEVELOPMENT OF AN INFRARED SIGNATURE ANALYSIS TECHNIQUE, A NON-DESTRUCTIVE TESTING TOOL.
E. Robert Britton (General Electric Co., Missile and Space Div., Valley Forge, Pa.).
In: Environmental Evolution, Volume I, 1967 Proceedings of the Annual Technical Meeting, 13th, Washington, D.C., April 10–12, 1967. Sponsored by Institute of Environmental Sciences. Mt. Prospect, Ill. Institute of Environmental Sciences 1967 p. 223–228.
(A67-34512)

Electronic sensing principles are applied to the environmental sciences by a nondestructive testing tool, an infrared signature analysis technique. Fault identification in fabricated electronic assemblies was studied, and an attempt was made to associate signature patterns with specific defect categories. Light activated silicon controlled rectifiers (LASCR) are discussed as GO-NO-GO sensors, although further development is required to make such LASCOPTIC sensors feasible. An inexpensive tellurium–gold sensor is considered feasible for laboratory use and comparable in accuracy to the evaporagraph, thermal plotters or IR scanners. This Te–Au sensor is not dependent on liquid nitrogen reference temperatures, and therefore does not require peripheral cryogenic equipment. M.W.R.

Review: Infrared radiation patterns have been receiving attention recently as a means of identifying faults in electronic circuits. In this role they have considerable potential as the basis of an important non-destructive testing tool. An introductory discussion of the fundamental principles regarding infrared radiation is followed by a description of the LASCOPTIC IR sensor and of the tellurium–gold IR sensor. Both of these sensors have apparently been developed by the author's company. The description is brief but well illustrated with photographs and thermal plots. The LASCOPTIC IR sensor has considerable potential but requires further development and implementation. The gold IR sensor is an inexpensive piece of analysis equipment which makes IR studies possible even in modest laboratories. The paper is a self-contained description, i.e., no references are cited. It will be of interest to design and test engineers seeking ways of diagnosing faults in electronic circuitry as well as to those who wish to further the use of infrared technology.

R68-13611 ASQC 844; 782; 830
DESIGNING TO AVOID FATIGUE IN LONG LIFE ENGINES.
Clarence E. Danforth (General Electric Co., Flight Propulsion Div., West Lynn, Mass.).
Society of Automotive Engineers, National Aeronautic Meeting and Production Forum, New York, N.Y. Apr. 25–28, 1966. 45 p. 18 refs.
(SAE-Paper-660311; A66-29836) Members, $0.75; Nonmembers, $1.00.

Control of vibration, emphasis on the cyclic character of engine operation accentuated by long life, the control of transient thermal response, and a constant sensitivity to the limitations of familiar measures of material strength in establishing permissible

levels of structural loads are key factors in assuring from the outset engines insensitive to fatigue for long life. Blade, accessory part, and overall system design are given as illustrations of vibration control. Thermal fatigue presentation is illustrated in terms of cooled turbine blading. The need to be mindful of the meaning of material strength factors in assuring high time, high cycle life engines is suggested in the treatment of cycling–rupture–vibration interactions. Increasingly precise analysis and experimental verification as an integral part of the design process make possible the increasingly complex design execution and attainment of design goals. Author (IAA)

Review: This paper cannot be read intelligently by anyone who does not have a good background in jet-engine design or in associated jet-component vibration studies. The paper appears to present the state-of-the-art with respect to analysis and cure of blade design problems resulting from vibration and high temperature. The cures are limited to using existing materials and slight modifications in existing design. Apparently failure results from a combination of creep and fatigue, giving emphasis to the need for fatigue data at elevated temperatures. The present blade design has a reasonable life and further improvement will come only from a slow painstaking process of design and material improvement. Methods to suppress vibration appear as one of the greatest needs, regardless of the engine component. No attempt has been made to provide definitions of the terms which are unfamiliar to anyone outside the jet engine design and testing field.

R68-13612 ASQC 844; 711; 712; 713; 782
MATERIALS CONSIDERATIONS FOR LONG LIFE JET ENGINES.
George J. Wile (General Electric Co., New York, N. Y.).
Society of Automotive Engineering Congress, Detroit, Mich. Jan. 10–14, 1966 14 p. 8 refs.
(SAE Paper-660057; A66-20155) Members, $0.75; Nonmembers, $1.00.

Outline of the major metallurgical factors that must be considered in selecting and developing high-temperature meterials for high-performance jet engines. Reliable behavior predictions for the metals used are difficult because of the long-time interaction of steady and cyclic stress in a corrosive environment at high temperature. The most immediate problems are the loss of strength and the reduction of ductility resulting from long-time high-temperature-stressed exposure of the nickel alloys used for hot parts. The structural changes involved in the agglomeration of strengthening precipitates and the formation of secondary phases are important problems. The formation of the acicular sigma phase is especially sensitive to the chromium content of nickel-base alloys. Low chromium content inhibits the formation of this phase but invites hot corrosion. Improved strain-cycling criteria are essential to designing for cyclic life. The Coffin criterion is adequate at low temperatures but nonconservative at turbine operating temperatures. IAA

Review: This is a good brief outline of major metallurgical factors that must be considered in selecting and developing high-temperature materials for long-life jet-engine applications. The scope of the paper is very broad; but there are sufficient details regarding stress–rupture, corrosion, thermal fatigue, erosion-oxidation, coatings, and microstructure stability to make it a useful reference for design engineers. The publication is primarily concerned with designs using nickel-base alloys, but many of the design concepts are applicable to steels and other common materials. The author points out some of pitfalls and mistakes commonly made by design engineers in the area of materials selection.

R68-13614 ASQC 844; 782; 824
A CUMULATIVE-DAMAGE CONCEPT FOR PROPELLANT-LINER BONDS IN SOLID ROCKET MOTORS.
K. W. Bills, Jr. (Aerojet-General Corp., Mechanical Properties Laboratories, Sacramento, Calif.), G. J. Svob, R. W. Planck, and T. L. Eriksson (Aerojet-General Corp., Sacramento, Calif.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1–3, 1965.) Journal of Spacecraft and Rockets, Vol. 3 Mar. 1966 p. 408–412. 7 refs. USAF-Supported Research.
(AIAA Paper-65-691; A65-14797; A66-24705)

Discussion of the problem of fatigue and cumulative damage evaluations to provide an experimental basis for the statistical application of a failure criterion. On the basis of experimental and theoretical studies, the applicability of the cumulative damage concept to the failure of propellant-liner bonds in test specimens is verified, and it is shown that the Miner's relation holds. It is found that log–log plots of applied stress vs time of failure are linear, frequency-dependent, and temperature-dependent. Damage ratios are cumulative and independent of sequence for the system tested. The applicability of this concept is demonstrated by application to a Minuteman Wing II second-stage motor with a hypothetical history. The useful life of the test data; (2) a structural analysis for static stresses caused by cure shrinkage, cooling, and gravity; (3) estimated transient stresses caused by transportation and handling; and (4) the statistical distribution of the moduli of propellant batches. Data from the Minuteman Wing II program are discussed. IAA

Review: This is a short paper which presents an approach for predicting cumulative fatigue damage to propellant-liner bonds in solid-propellant rocket motors. The paper is well written and contains useful engineering design information for the effects of temperature, stresses, and load frequency on bond life. Miner's equation for linear cumulative damage (based on the time spent under stress) is substantiated for these motors. There are situations, of course, in other materials and applications where it does not hold. In general, the results and conclusions are reasonable and substantiated. One conclusion, however, is somewhat "commercial" and another conclusion is quite obvious.

R68-13618 ASQC 844; 775
SERVICE CORRELATION—THE KEY TO SUCCESSFUL NON-DESTRUCTIVE TESTING.
R. W. Smiley (U.S. Navy, Polaris Missile Facility Pacific, Bremerton, Wash.).
(American Society for Testing and Materials, Symposium on Nondestructive Test Methods for the Aerospace Industry, Seattle, Wash., Nov. 5, 1965.) Materials Research and Standards, Vol. 6 Mar. 1966 p. 149–154.
(A66-23649)

Description of a nondestructive testing (NDT) system for the Polaris missile. It is proposed that there are six successful steps for a good NDT program: select those attributes that must be examined, try known NDT techniques on selected attributes, verify the validity of techniques, establish the effect on performance of measurable anomalies, select the best NDT techniques, and eliminate redundant NDT tests after production has started. Seven common pitfalls to be avoided in the development of a NDT program are listed. IAA

Review: This is an excellent paper on the principles involved in nondestructive testing (NDT). It is not a paper that discusses test methods per se, but it gives a penetrating analysis of what should be done, what should not be done, and why. For example, it is emphasized that not everything that can be detected during

NDT will contribute to failure; and that an extensive program of testing needs to accompany the application of any particular technique, so that anomalies can be properly classed as either failure-causing and thus to be eliminated, or nonfailure-causing and to be ingnored. Another very practical point which the author stresses is that apparent anomalies which show up in one method of NDT need to be checked either by direct inspection or by other methods of NDT because the anomalies may be associated with a test technique rather than with the material itself. This is an engineering paper, not a physics of failure paper, and as such treats the trade-offs that must be made, the compromises that cannot be made, and in general puts the engineering use of NDT in an excellent perspective. It is highly recommended reading for those who want to know how NDT can be of help in their engineering problems.

R68-13619 ASQC 844; 090

SECOND BREAKDOWN—A COMPREHENSIVE REVIEW.

Harry A. Schafft (National Bureau of Standards, Electron Devices Section, Washington, D. C.).

IEEE, Proceedings, Vol. 55 Aug. 1967 p. 1272–1288. 133 refs. (A67-39248)

Review of the published literature dealing with the phenomenon of second breakdown in semiconductor devices and the problems it creates in the design, fabrication, testing, and application of transistors. This study is concerned with second breakdown in diodes and other devices, in general, to the extent that it relates to a better understanding of second breakdown in the transistor. The discovery and gradual increase in knowledge of the phenomenon of second breakdown are reviewed, and measurement methods and techniques including sinusoidal sweep, rectangular pulse, inductive sweep, and the detection of current nonuniformities are studied. Topics discussed include delay time and triggering energy, p–n–p–n action and surface phenomena, pinch-in effect, design deficiencies and material defects, lateral thermal instability triggering temperature, electrical effects, interacting factors, magnetic effects, and nuclear radiation. The second-breakdown mode is outlined, and the maximum safe operating conditions are discussed. IAA

Review: This review paper has no competition in that no one other than its author has attempted to prepare such a comprehensive description of second breakdown. (This paper updates a similar review of a year earlier [1].) A more complete and current text and bibliography on this subject do not exist in the open literature. This paper should now be the starting reference for readers wishing to acquaint themselves with second breakdown phenomena and contemporary thinking regarding it. The author chooses to emphasize second breakdown in transistors because "the second breakdown problem is greatest in transistors." Such an approach tends to obscure the relationship between the thermally-actuated, second breakdown-like effects reported in simpler structures and those of transistors in which adequate analysis requires solutions to two- or three-dimensional current flow problems. Such solutions in general do not exist and the transistor analysis must of necessity be less complete than is possible for the simpler structures. Clearly the author feels that this simpler approach is less rewarding and less realistic—the complicating features of transistors are the very features that make second breakdown significant. The author's description of contemporary understanding of second breakdown is one of discord and lack of agreement. Investigators cannot even agree on a rigorous definition of second breakdown. This review paper is more of a history saying who did what and when than a unifying exposition of the subject in which many diverse observations fall logically into place. The latter, the author implies, does not now exist.

Reference: [1] H. A. Schafft and J. C. French, "A survey of second breakdown." *IEEE Trans. Electron Devices,* vol. ED-13, pp. 613–618, Aug/Sep, 1966

R68-13620 ASQC 844

THE FAILURE OF PLASTICS INSULANTS DUE TO SILVER MIGRATION.

B. H. Conen (Post Office Research Station, England).

Post Office Electrical Engineers' Journal, Vol. 58 Jan. 1966 p. 245–248. 5 refs.

Basic phenomena are reviewed in relation to insulation failure in plastics due to silver migration from the connections used in telecommunication circuits. The occurrence of exchange faults due to silver migration is discussed, along with alternatives to the use of silver electrodes and phenol-formaldehyde resins. Physico-chemical tests are suggested for the selection of new plastics, with accelerated life testing or actual field trials to confirm selection; and testing results and proposed test limits are tabulated for a number of plastic materials. The importance of design in minimizing migration is noted, as environmental effects. The use of silver–copper alloys is considered a possible deterrent, and the limitations of chemical tests on materials are discussed. M.W.R.

Review: This is a good paper on the physics of failure concerned with silver migration on plastic insulation. It gives a good review of the silver migration problem and goes on to cite the experiments which were run and the conclusions which were drawn. The conclusions appear reasonable and relate to design practices where silver can migrate along the insulator. An interesting aspect of the paper is its discussion of accelerated testing and its pointing out that the acceleration factor was not the same for all the materials, that is, one of the tests was much too severe for one of the materials. This material, perversely, then showed up much better in the field trials than it had in the accelerated tests, compared to the others. For those who are not familiar with the silver migration problem and would like to learn more, reading the introduction titled "Silver Migration" and the conclusions (which altogether form just one page) will be an excellent way of getting up to date on the problem.

R68-13621 ASQC 844

DEGASSING IMPROVES QUALITY, EXTENDS FATIGUE LIFE OF STEEL.

A. A. Conrad, C. W. Darby, R. T. Morelli (Crucible Steel Co. of America, Midland, Pa.), and Daan Troost (Federal-Mogul-Bower Bearings, Inc., Los Alamitos, Calif.).

SAE Journal, Vol. 74 Mar. 1966 p. 53–56. 3 refs.

Degassing techniques are discussed that improve quality and extend the fatigue life of steel. Because it is largely free from flaking and internal rupturing in large ingots and forgings, vacuum degassed steel has ideal properties for large steam turbines or generator rotors as well as for smaller scale high-load bearings. The degassing technique results in reduced content of gas and nonmetallic inclusions, more homogeneous structure, and better control of alloy composition. Average transverse ductility is illustrated with and without degassing, and results are presented for some typical bearing fatigue life tests at various stress levels. M.W.R.

Review: This article builds a strong case for the use of vacuum degassing of several steels. The results, which indicate improvements in internal quality, fatigue life, and ductility, are well illustrated. The reduced content of gas and nonmetallic inclusions, improved control of alloy composition, and a structure that is more homogeneous are given as reasons for the improved fatigue life of vacuum degassed steels. Three main processes for producing such steels are clearly illustrated and explained. While the test results show the superiority of the vacuum degassed steels over air-cast steels, no attempt is made to present an explanation of why this superiority exists. The paper suggests that inclusions play an important role in fatigue crack initiation. However, no comparison figures are given for reduction in size, number, or type of inclusions

that result from vacuum degassing. Also of interest would be the extent to which the control of alloy composition affects fatigue. If comparison is made at the same hardness level, alloy composition usually has little, if any, effect on fatigue life. At any rate there is little question, based on the results presented, that a significant improvement in fatigue life can be obtained through the use of this process, regardless of the reasons why. The article is well written, short, and to the point.

R68-13622 ASQC 844

WHY LASERS FAIL—AND WHAT TO DO ABOUT IT.

Glenn A. Hardaway (Applied Lasers, Inc., Stoneham, Mass.).
Microwaves, Vol. 5 Apr. 1966 p. 46–48, 52, 54.
(A66-27669)

Consideration of the major causes of failures of solid state lasers, giving design guidelines which—if followed—will permit designer to construct glass or ruby systems good for up to 500,000 discharges. Failures in ruby and glass lasers can often be traced to flash lamps, the laser rod, the cavity material, excessive heat in the lamp and rod, and dirt in the cavity or on components. Each of these possible causes is discussed in some detail, and methods of correction and prevention are suggested. IAA

Review: This paper is among the first to discuss the failure modes and mechanisms for lasers. Most of the material is concerned with high-power lasers. The cautions and their explanations appear reasonable. Further articles on this subject will help to clarify the entire situation and will give both users and manufacturers the benefit of everyone's experience. This particular paper has two difficulties. In the introductory paragraph it suggests that 500,000 discharges can be available, but in the individual discussions 100,000 is the highest number mentioned. The rise time of the current is expressed in milliseconds and apparently should have been microseconds. Otherwise a 1-millisecond pulse is supposed to have a 100-millisecond rise time.

R68-13625 ASQC 844; 770; 782

THE USE OF STANDARD SEQUENCES IN ENVIRONMENTAL TESTING.

R. T. Lovelock (Belling and Lee, Ltd., Enfield, England).
(Conference on Reliability and Environmental Testing of Electronic Components and Equipment, College of Technology, Letchworth, England, May 3, 1967, Paper.) The Radio and Electronic Engineer, Vol. 34 Sep. 1967 p. 185–191. 6 refs.

The desirability of using two or more individual testing procedures in sequence is discussed in relation to cases of equipment failure that would not occur when any one of the individual testing procedures were applied. The objects of environmental testing are reviewed; and climatic and mechanical environments are considered by themselves and in various combinations. Specifically, attention is given to temperature and humidity, thermal shock, mechanical stress and strain, and general failures due to climate. A typical sequence of tests for electronic components is tabulated; and standardization procedures for and the economics of comprehensive testing are discussed. M.W.R.

Review: This paper is addressed to an important consideration in environmental testing, i.e., those situations in which a sequence of adverse conditions can lead to failure which would not occur under the individual conditions applied separately. Related to this and also considered are cases in which a first procedure does damage which is detected only upon subsequent application of a second procedure. The paper is a description, based on the testing laboratory experience of the author and associates, and is illustrated with practical emphasis. For those who desire details on specific sequences or their basis, six references (mainly British Standards) are cited. The paper itself conveys mainly a general awareness of the fundamental considerations which are involved.

R68-13626 ASQC 844; 711; 714; 782

METALLURGY AND THE NEW CORROSION ENGINEER: WHAT HE SHOULD KNOW ABOUT CORROSION-INDUCED BRITTLE FAILURES.

M. E. Holmberg and T. V. Bruno
Materials Protection, Vol. 5 May 1966 p. 8–15. 15 refs.

Causes of corrosion-induced brittle failures in various metals are discussed, and the six general types of brittle failures are noted. These are corrosion fatigue, intergranular corrosion, stress corrosion cracking, hydrogen-induced failures, sulfide stress cracking, and stress alloying. Corrosives which induce intergranular corrosion are tabulated as are the environments which cause stress corrosion cracking of various alloys. Mild steels, high strength steels, hardenable stainless steels, austenitic stainless steels, copper alloys, aluminum alloys, and titanium alloys are considered. Hydrogen-induced alloys are discussed in terms of hydrogen embrittlement, delayed failure, and high temperature attack. M.W.R.

Review: This paper is a good one for the new design engineer who will be working with mechanical systems. Some of the more experienced engineers might find some profit in reading it also, or at least skimming through it just to refresh their memory on some long-forgotten items. The article is largely an encyclopedic treatment of causes of failure associated with corrosion or corrosion-like environments. As such, in the reliability engineer's parlance, it would be associated with reliability physics or failure mechanisms. While other authors might have a slightly different set of topics to treat under this heading, the present selection cannot be faulted and can be very valuable reading. It is short, does not use unduly technical language, and is easy to read.

R68-13628 ASQC 844; 711; 712

HOW DANGEROUS ARE WELD DEFECTS?

Richard Weck (British Welding Research Assn., Cambridge, England).
Metal Progress, Vol. 92 Sep. 1967 p. 93–98.

The complexity in appraising tolerance levels for defects in welded structures is stressed; and with thicker materials the position of the defect in relation to the joint surface is an important factor. The location of a defect in a field of tensile or compressive residual stresses may influence the effect of the defect on both fatigue strength and brittle fracture strength. However, many other factors must be considered in assessing weld reliability. Defects and failures are considered in this light, as are stress concentrations caused by defects, brittle factors, failures due to fatigue, and design considerations in welded structures. Fatigue life of pipe welds is discussed. M.W.R.

Review: This is a good article because of the perspective it gives on evaluating defects in general as well as the direct commentary on welding defects. For very high reliability applications one is probably willing to tolerate fewer apparent defects even though their effects are thought to be negligible just on the principle that the fewer things there are around that can go wrong, the fewer things will go wrong. There are some people, usually in a nonmanufacturing operation, who feel that no apparent defects should be allowed, but they are generally living in an ivory tower and have not clearly thought out the meaning of the word defect. In fact, much of the confusion probably arises from this word. If it is interpreted to mean any departure from homogeneity, as it sometimes is interpreted, then, of course, the world is full of

defects. When it is understood to mean any inhomogeneity that is likely to cause failure, the problems associated with the interpretation of the word are likely to be the source of much confusion and controversy. The paper is a good one and is well worth reading by design and reliability engineers in the mechanical fields. There are undoubtedly experts who would argue with some of the exact conclusions, but for aerospace reliability the philosophy presented in the paper is much more important than any of the details per se.

R68-13629 ASQC 844; 775

NON-LINEARITY EXPOSES BAD ELECTRONIC COMPONENT PARTS.

E. Martensson (SAAB Aktiebolag, Electronics Laboratory, Goteborg, Sweden).

Electronic Components, Vol. 8 Apr. 1967 p. 371–373.

Test results show that measuring the third harmonic generated in resistors, capacitors, and inductors often exposes possible likelihood of failures during subsequent operations; and to accomplish this, a component linearity test apparatus is used that is essentially a low-frequency generator giving a very pure fundamental voltage combined with a selective amplifier for the third harmonic. Generated harmonics in resistors are discussed, and a hypothetical failure cause is considered. Changes in resistance and third harmonic voltages are tabulated for 30 resistors of a test batch that have exhibited atypical values. M.W.R.

Review: This is one of several papers which espouses the cause of using non-linearity in the voltage–current curve of an electronic component, usually a resistor, to show whether it contains flaws which are likely to cause a short life (see, for example, R67-12902, R67-13486, and the paper by Kirby in *Electronics Components,* May 67, p. 511–515). The present paper shows measurements on resistors. In practice a constant alternating current of very high purity is applied to the device and the third harmonic voltage which is generated is measured. Obviously, for this technique to be successful, the component must be nominally a linear one, which leaves out virtually all so-called active components. This technique should certainly be explored further to determine the extent of its applicability and the ease of its use in both production and laboratory situations. It is likely to be limited to discrete components. Certainly it would not be applicable at all to any of the components in silicon integrated devices.

R68-13630 ASQC 844

EFFECT OF SURFACE FILMS ON FATIGUE LIFE OF STEELS.

P. C. Clarke and M. M. B. Kay (AMETEK, Inc., Hunter Spring Div., Hatfield, Pa.).

Materials Research and Standards, Vol. 5 Dec. 1965 p. 600–606. 13 refs.

(A66-15483)

Study of an experimental investigation concerning carbon and stainless steels tested in a rotating beam fatigue-testing machine, after they had been cleaned and had received other surface treatments. It was found that cleaning decreased fatigue life relative to the as-received condition, if the cleaning removed a surface coating. The most effective cleaning processes were found to be vapor degreasing and wiping with acetone. It is concluded that surface films of medium machine oil and water-displacing, rust-preventative oil on cleaned specimens increased fatigue life. It is noted that plating or weathering were found to reduce fatigue strength. IAA

Review: The results of numerous laboratory fatigue tests to evaluate the effects of surface films on the fatigue life of steels are reported. The average fatigue curves were fitted to the data points by "eye estimate" rather than by statistical calculations. But, because of the large number of individual data points obtained for the various test conditions, this method of curve fitting appears to be adequate for this work (i.e., only the average response is of interest). The paper is not highly technical, but it is of practical interest to the design or development engineer.

R68-13636 ASQC 844; 782

EVALUATION OF FATIGUE CAPABILITIES ON HIGH PERFORMANCE MILITARY AIRCRAFT.

E. D. Bouchard (McDonnel Aircraft Corp., St. Louis, Mo.).

Pacific Area National Meeting of the American Society for Testing and Materials, 5th, Seattle Oct. 31–Nov. 5, 1965 72 p. 1 ref. (ASTM Paper-24)

Techniques are outlined for evaluating airframe fatigue occurring on high performance military aircraft, and the inadequate definition of the repeated flight load environment to which the vehicle is exposed during its service life is considered by the most serious problem in making such evaluations. Another problem is in the lack of a firm definition of weapon system capability to sustain a given repeated load environment. A summary is presented of a program for accumulating flight load maneuver data on F4 series aircraft, and a statistical interpretation of scatter in load factor counts among individual aircraft is included. The F4 fatigue test program is reviewed to show techniques that can be used to establish expected fatigue strength and to evaluate parameters which may produce significant deviations from predictions based on an orderly spectrum. The combination of scatter in repeated load histories among individual aircraft and scatter in test results is considered; and a comparison is made of the load factor spectrum used in several fatigue development programs with available flight load maneuver data. M.W.R.

Review: This paper gives an approach to and an analysis of the design problems associated with the measurement and use of environmental load histories. These histories were obtained from a systematic program over a long period of time for a number of similar aircraft and over a variety of operational conditions. The scatter of such data in an individual aircraft as well as the overall scatter in a large fleet of similar aircraft has been established. When such scatter was combined with the scatter in test results, a combined scatter factor emerges which can be used to establish the probability of failure for a given series of aircraft over a wide range of operational conditions. The paper demonstrates clearly that the design of military or other aircraft is dependent on how well the scatter of operational loading and test data is known. The scatter is also related to Mach number and altitude to provide a more complete history of peak loadings. As a greater backlog of such flight information becomes available, both the statistical load distribution and the more significant parameters will be better known, thereby providing a higher engineering confidence in the ability of a given type of aircraft to withstand the stresses. This paper is clear and extremely well documented.

R68-13645 ASQC 844; 830

Radio Corp. of America, Princeton, N. J. Astro-Electronics Div.

EFFECT OF STRUCTURAL FATIGUE ON MECHANICAL DESIGN OF SPACECRAFT

Joseph J. Frank *In its* Space Electron. [1965] p 61–63 refs (See N66-19827 10-31)

(N66-19841)

In the mechanical design of spacecraft, it is very important that the fatigue effects on the structure be thoroughly considered during the design process. This paper briefly discusses input loadings

and responses (including construction of an experience table), theoretical analysis of fatigue stresses, and then presents a practical satellite design problem to illustrate the design process followed. Author

Review: An analytical approach for determining the allowable fatigue stress in satellite design is given in this paper. Of particular interest are expressions which relate Gaussian noise and sinusoidal-sweep load input with Miner's hypothesis for cumulative fatigue in a manner which results in the prediction of the allowable fatigue stress in the design stage. The reader must be familiar with vibration-type loading and testing to understand this paper. No attempt has been made to explain how the "fundamental" equations were derived and they will be unfamiliar to many. The paper is short and will be of interest primarily to those engaged in vibration testing.

R68-13646 ASQC 844; 711; 712; 713

National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va.

FATIGUE LIFE UNDER VARIOUS RANDOM LOADING SPECTRA

Sherman A. Clevenson and Roy Steiner *In* NRL Shock and Vibration Bull., No. 35, Pt. 2 Jan. 1966 p 21–31 refs (See N66-17786 08-32)

(N66-17788)

A study of the fatigue life of aluminum-alloy specimens under various random loading spectra has been conducted. It was indicated that for the three spectra considered, $\phi(\omega) = K_1\omega^{-2}$, $K_2\omega^0$, and $K_3\omega^{+2}$, there was essentially no difference in fatigue life. The effect of the ratio of peaks to zero-mean crossings was found to be negligible in the range of ratios investigated. The results of the investigation indicated that the linear cumulative damage theory was very unconservative, especially at the low stress levels. Fractograph studies showed qualitatively the expected types of failure wherein the outer sections of the specimen failed due to fatigue and the inner area failed due to tensile loading. Author

Review: Trends and gross effects from exploratory laboratory fatigue tests on randomly loaded and sinusoidally loaded aluminum specimens are reported. Random loading, as studied in these tests, denotes true randomness in both amplitude and frequency. The test results, in general, might have been predicted. The wide variations in fatigue lives which are usually attributed to adding or deleting one or more high loads early in the specimen life time were not encountered in this work. The specimen shape or geometry may not have been sensitive to this condition; or, perhaps, an insufficient number of tests were run at the various root-mean-square stress levels, under these random conditions, to give both high loads and low loads early in the specimen life. A more detailed explanation for the unusually high static tensile strength of the test material would have been informative to some readers. The data presented illustrate the possibilities of using sinusoidal fatigue data which have been arbitrarily reduced by an order of magnitude as a first order approximation for design of randomly loaded components. Certain portions of the reproduced copy of the paper (N66-17788) are difficult to read. NASA Technical Report TR R-266 dated September 1967 and by the same authors is of greater scope and gives more details of the investigation than the subject paper.

R68-13647 ASQC 844; 711; 712; 713

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF LOAD ALTERNATION ON THE FATIGUE STRENGTH AND LONGEVITY OF COMPONENTS WITH AND WITHOUT STRESS CONCENTRATION. COMMUNICATION II

V. M. Grebenik and V. F. Kucherenko 3 Dec. 1965 14 p refs Transl. into ENGLISH from Izv. Vysshikh Uchebn. Zavedenii, Chern. Met. (Moscow), No. 8, 1964 p 188–194

(FTD-TT-65-1071/1+2; AD-625147; N66-19956) CFSTI: HC $3.00/MF $0.65

Fatigue strength and stress regimes of notched and smooth specimens of carbon steel and alloy steel were tested by cyclic alternating loads of increasing durations and by a single-step, one-time change in the load cycle. The final number of stress cycles that the specimen withstood in working to failure was determined by varying the duration of the initial condition, the stress difference in load levels, and the final number of load stress cycles. It was found that cyclic load fatigue strength variations depended heavily on the steel properties. Carbon steels showed a higher cyclic strength than alloy steels; soft low-carbon steels were less sensitive to cyclic loads than strong and hard steels. Increased stresses resulted in higher softening effects for all tested specimens; smooth specimens showed a stronger softening effect under a single-step, one time load change than the notched samples. G.G.

Review: This is an unedited rough draft translation from the Russian which is difficult to read and understand because of incorrect words and unusual sentence structures. It is not recommended as a reference because there are excellent papers written in English which cover the subject. If one persists, however, in a desire to read this translation, a previous paper by the same authors is necessary for a complete understanding of the work—steel composition, test procedures and conditions, data analysis techniques, etc. Furthermore, there are no indications as to how the curves were fitted to the data. For example, the curves could have been fitted to single-point data, to average values for replicated data, or to some calculated percentage of survivors for replicated data by "eye estimate" or statistical calculations.

R68-13648 ASQC 844

General Dynamics/Convair, San Diego, Calif.

A METHOD FOR ESTIMATING THE FATIGUE LIFE OF 7075-T6 ALUMINUM ALLOY AIRCRAFT STRUCTURES

Clarence R. Smith Philadelphia, Pa. Naval Air Eng. Center Dec. 1965 70 p refs

(Contract N156-41307)

(NAEC-ASL-1096; AD-632123; N66-29250) CFSTI: HC $3.00/MF $0.65

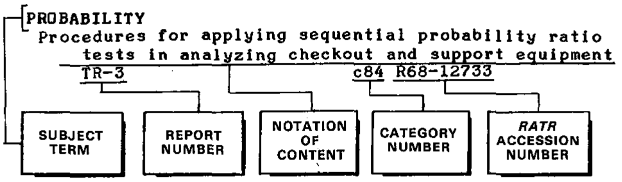
The purpose of this investigation was to assess the validity of the "Smith Cumulative Damage" hypothesis for 7075-T6 aluminum alloy specimens and structures. It was found that the results of a single-amplitude test (at short life) can be used to estimate the stress at the point of failure, including residual stress. This permits using S-N data for axially loaded unnotched specimens to predict spectrum life. Excellent agreement was found between calculated and experimental lives of full-scale structures; however, test lives of small specimens were consistently shorter than predicted. Author (TAB)

Review: The paper presents extensive test results from a laboratory investigation to assess the validity of a cumulative fatigue damage hypothesis for aircraft structures. The author does an excellent job of explaining his concept; he substantiates his work with numerous test data and illustrates the application of his theory. The validity of this cumulative damage hypothesis for materials other than aluminum or structures other than aircraft, e.g., ground vehicles and power transmission equipment, remains to be substantiated. In general, the paper is sound and the results and conclusions are reasonable and of current practical interest to engineers involved with the design of aircraft structures. Test engineers concerned with materials and structures other than those evaluated should use this cumulative damage theory with caution.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 2

Typical Subject Index Listing



The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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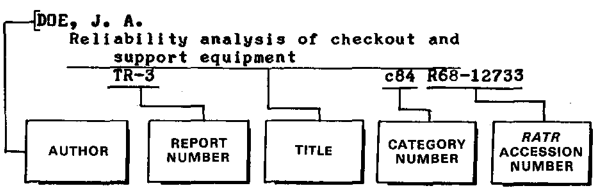
PERSONAL AUTHOR INDEX

Typical Personal Author Index Listing



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REPORT AND CODE INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 2

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB*, *STAR*, and *IAA*, respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 2

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This list of *RATR* accession numbers may be used to identify the category in which a numbered abstract-review appears in the abstract section of this journal. Accession numbers are arranged in ascending order. Preceding each accession number is the category number for locating the abstract-review in the abstract section of *RATR*.

c84 R68-13605
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Reliability Abstracts and Technical Reviews

March 1968

Volume 8
Number 3

R68-13655—R68-13705

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

ASQC CODES
***RATR* ACCESSION NUMBER**
CORPORATE SOURCE
TITLE
PUBLICATION DATE
AUTHOR

R68-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65

CONTRACT OR GRANT
***TAB* AND *STAR* ACCESSION NUMBERS**
REPORT NUMBER
SALES AGENCY AND PRICE

***RATR* ACCESSION NUMBER**
ASQC CODE
TITLE
AUTHOR AND AFFILIATION
JOURNAL REFERENCE
***IAA* ACCESSION NUMBER**

R68-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A68-12569)

***RATR* ACCESSION NUMBER**
ASQC CODES
TITLE
AUTHORS AND AFFILIATIONS
CONFERENCE OR SYMPOSIUM REFERENCE
AVAILABILITY AND PRICE
***IAA* ACCESSION NUMBER**

R68-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A68-12407)

VOLUME 8 NUMBER 3

Reliability Abstracts and Technical Reviews

A Monthly Publication

of the National Aeronautics and Space Administration

March 1968

80 RELIABILITY

R68-13656 ASQC 800; 520; 770; 823

IMPROVE YOUR RELIABILITY.

Adolph J. Hitzelberger (Motorola Inc., Franklin Park, Ill.).

Industrial Quality Control, vol. 24, Dec. 1967, p. 313–316. 5 refs.

Use of statistical techniques in combination with engineering know-how is shown to result in increased product reliability, and the integration of statistical techniques into an industrial reliability program is mentioned. Failure prevention techniques and a qualitative method of overstress testing are also discussed. Results of a factorial experiment for studying circuit components are tabulated, and examples of identifying cause and effect are included. M.W.R.

Review: This is a qualitative article which shows, by means of examples, some of the relatively simple techniques which can be used in improving reliability. The philosophic use of these techniques stems from the idea that it is best to get the big problems out of the way before worrying about the little ones. Step-stress testing of the "probe" technique is illustrated. In this process the severity level is considered to be made up of several stresses and each step is made up of an increase in each of the several stresses; for example, temperature, vibration, and supply voltage are increased together. This is a qualitative test intended to find out what kinds of things can go wrong. It is to be followed by tests at severity levels below those at which failure occurred in order to get quantitative results. The article will be helpful to management personnel who wonder just what a basic reliability effort can do for their groups and it will be useful to engineers who do not yet regard the life of a piece of equipment as an important design consideration.

R68-13668 ASQC 800

NAVY RELIABILITY RESEARCH.

Harold Liebowitz (U. S. Navy, Office of Naval Research).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Coca Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 34–53. 1 ref.
(SAE Paper-670614)

Current Navy research programs in reliability are reviewed in order to identify those programs and requirements that will achieve a balanced basic research effort related to weapons systems development. Research efforts that require continuing support are in the areas of engineering, probability and statistics, human factors, systems analysis, and management of data and procedures. Reliability goals are discussed in terms of the overall Navy reliability mission and in relation to cost effectiveness; and examples are included of research areas in the Navy that might make important contributions. Present research efforts at various bureaus and offices are noted, along with the apparent gaps in naval reliability programs. A summary of problems indicated by commands is considered under the headings of flight vehicles, human reliability, information systems, operations research, ship machinery, underseas vehicles, and quality control. M.W.R.

Review: Reliability is used in this paper in the broad sense, in the same vein as one says that reliability is everybody's business. Included are the engineering, mathematical, behavioral, systems analysis, and management areas. The paper at first appears to be unnecessarily long, but it turns out that most of the length comes from the listings of various subjects bearing on Naval reliability research. Those concerned with either reliability research or Naval reliability will find this paper informative. It also could serve as a source of ideas for reliability research topics for contractors interested in areas to pursue or for graduate students interested in possible thesis topics.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13657 ASQC 810; 870

RELIABILITY AND MAINTAINABILITY—A SERIES OF FIVE ARTICLES.

J. J. Jaklitsch, Jr., ed.

Mechanical Engineering, Feb.–June, 1966, p. 1–15, 17–24. 8 refs.

The basic problem of reliability and maintainability is discussed; and separate articles consider reliability and maintainability from the viewpoints of the automotive industry, aviation design, military logistics, and space flights. The general discussion deals

with reliability as both a probability and as a function of time, the engineering approach for product development, and sampling techniques. Uniform reporting of failure data and uniform parts grouping are discussed as automotive reliability tools; and laboratory and proving ground testing, interpreting test results, specifying reliability, and customer feedback are considered. Maintenance costs are considered for aircraft; and it is noted that high maintainability, simplicity, and commonality of design, with emphasis on reliability, were built-in to the development of the DC-9 aircraft. Value engineering, incentive contracting, contractor performance, quality assurance, zero defects, and defense contract administration are considered for military logistics. Sample space mission requirements, subsystem requirements and predictions, crew safety, and availability are discussed in the article on space travel. M.W.R.

Review: This is a collection of five articles, published serially, to portray the problems of reliability and maintainability to design and production engineers. Since they are written by five different authors, there is a variability in tone and emphasis as well as in subject matter. They deal with selected topics in reliability and maintainability, some of which overlap and which leave some areas not covered. The first paper, which presents the basic problem, is by an author who has published extensively in this field and who has rather definite ideas on what should and should not be done in reliability. Some of the ideas are controversial in degree, if not in principle, but this does not detract from their usefulness—many good ideas are controversial. It will be easy for the novice reader to get an unbalanced view of the reliability field from this paper since he does not have the depth of experience to interpret many of the remarks. It is uncertain what the author expects of statisticians, especially since the difficulty is rarely what statisticians do, but what engineers do with statistics. Very often the engineers have abdicated their responsibilities in this area to the statisticians, so when engineers get burned it is a little presumptuous to cry foul. The author does rightly emphasize that reliability and maintainability are primarily engineering problems. But until engineers know how to convert their knowledge to numbers they cannot expect statisticians to help arrange these numbers to make them useful for reliability. The definition of reliability as a probability is deplored by the author. It has turned out to be not a useful one partly because the probability is not operationally defined. The mathematical theory of probability has application to at least two different fields, viz., relative frequency and degree of belief; the overlap between these two fields is not clear. If this paper is read to get an understanding of the problems it raises rather than as the last word on any of these problems, it can be helpful. The second paper is quite similar to the one covered by R66-12813 and the review for it is reproduced here. "This appears to be a soundly conceived reliability program. The idea of having the design engineer concerned with reliability is a good one since it is he who must meet the other design criteria and make the necessary tradeoffs. No mention is made of design reviews which can be effective economical tools for seeing that design requirements are being met in a reasonable way. The mathematical techniques are intentionally rather simple: a good tradeoff between ease and likelihood of use vs. exactness. Of course it is impossible to tell from the paper what the program is really like. In many such descriptions there is often an element of describing what one would like the program to be." In contrast to the first paper, where the author states that time cannot be speeded up and that increasingly higher stresses should be used, this author states the reverse; i.e., for a complex system such as an automobile, time is effectively speeded up by more frequent application of the larger service loads. It is poor practice to label the overlap on a frequency plot of stress and strength as the probable failure area. It is too easy to misinterpret the label as meaning that the probability of failure is the area beneath the intersection of the two curves. The third paper deals largely with maintainability through an example of the DC-9 aircraft. Although maintainability is often considered a separate discipline from reliability, if a system is easy to maintain, it will probably be more reliable since the maintenance will be done better. In addition, many things which contribute to ease of maintainability, such as standardization and simplicity, can also contribute substantially to reliability. The fourth paper is largely a listing, with some explanation, of each of the various policies of the DOD which are promulgated in an effort to pay attention to its own details, so that it does what it wants. The paper is important because it represents an official point of view from the largest customer that many companies have. It is worth pointing out that policies do not implement themselves but are implemented by people. The implementation of many of these policies is not always effective for that reason. Problems do exist on both sides of the DOD/supplier fence and continuous exposure of them is necessary. It is idealistic to expect many negative comments from suppliers on important contractual points. The people who are implementing DOD policies may become offended personally, and thus not be so likely to reward a complaining company with a contract in the future. Thus, DOD should pay extra attention to the real world in which its policies must compete and be effected. Part five, the last part, discusses long-range manned interplanetary flight and shows how the reliability–maintainability requirements are affected by the rather different nature of the mission. In this respect the problems are more pertinent to ocean-going ships than to aircraft. The author's discussions of the trade-off between ease of maintenance and reliability are good. This dilemma is difficult to solve unless someone gets a bright idea which will decrease maintainability and increase reliability at the same time. No brand new concepts are introduced in this paper, but those discussed are not the ones associated with most defense and short-term space flight requirements.

R68-13663 ASQC 815; 122; 130; 817; 824; 833; 837

SPECIFYING THE DESIRED DISTRIBUTION RATHER THAN MAXIMUM AND MINIMUM LIMITS.

Irving W. Burr (Purdue University, West Lafayette, Ind.).

Industrial Quality Control, vol. 24, Aug. 1967, p. 94–101. 7 refs.

A case is made for specifying the desired distribution for parts dimensions rather than using maximum and minimum limits; and these distributions are set in conjunction with tolerances allocated by the design engineer. The proposed method is considered to have the advantages of wider variability in production, savings in inspection time and scrapping, and producing assemblies that meet design engineering specifications. Characteristics for an assembly and variation of the characteristic assembly are discussed; and considerations for process controls and tests to achieve the desired distributions are included. A summary of the approach from the design engineer's viewpoint is given; and the cases of erratic assignable causes and consistent change in process level are considered. M.W.R.

Review: The case presented in this paper for specifying the desired distribution of characteristics of component parts rather than their maximum and minimum limits is worthy of consideration by design engineers and others concerned with specifications for high-reliability equipment. The paper is a competent treatment of the problem. By specifying a distribution the author basically means specifying the mean and variance of the distribution. The mean and variance relationships given in the paper apply whether the distributions are Normal or of some other form. It is necessary that the distribution form be known only when particular probabilities are specified. Certain questions will have to be carefully considered before implementing the approach described in this paper. The relative costs and possible internal savings of the two specification procedures must be estimated. In some businesses lack of control may result in higher costs for specifying the distribution

form or certain characteristics of the distribution rather than the extreme limits. To estimate the costs will require consideration of the frequency of sampling for control, the number of critical parameters, and the number of items to be measured for compliance with the specification.

R68-13671 ASQC 810
VOYAGER'S MOST CHALLENGING SYSTEM REQUIREMENT.
B. H. Caldwell (General Electric Co., Missile and Space Div., Valley Forge, Pa.)
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., p. 101–103. 4 refs.
(SAE Paper-670621; A67-34656)

Results of systematic studies of flight failures occurring in complex unmanned spacecraft in connection with the requirement that the Voyager spacecraft achieve success on the first try. It is found that one-third of the flight failures are in simple components, electromechanical components have a failure rate twice that of electronic components, "off-the-shelf" components fail almost twice as frequently as those designed specifically for the program in which they are used, design deficiencies account for about half of all flight failures, ignorance of the space environment is an insignificant cause of flight failures, and first-day failure is a serious problem. IAA

Review: Brief notes are given in this paper on three areas related to first-try success programs. Voyager enters in as an example of this type of program. For the benefit of those readers who may have become lost in the maze of program names, Voyager is a deep space effort currently in the early planning stage. The first area commented on has to do with a number of responsibility "musts" for government and/or the contractor. These are indeed challenging but invariably this type of discussion has motherhood and flag flavor and, thankfully, the points are brief. The second area is a short outline of the findings of a study on actual spacecraft flight failure causes. This is the most interesting of the three areas. Many persons would undoubtedly like to see more information on this but no references are given. Perhaps this is in some way related to the paper covered by R67-13327. The third area is the management approach to reliability at the General Electric Company's Missile and Space Division. It is called a "Tops Down" management approach. It sounds great! Reliability workers of a decade or so ago will possibly find this unbelievable; for example, effects on mission success are to come ahead of cost and schedule. Few persons outside those intimately associated with this organization will really know whether this is a sales-pitch statement or whether (and hopefully) this is a new management era with respect to reliability.

R68-13675 ASQC 810; 816
INTRINSIC TO OPERATIONAL RELIABILITY AND MAINTAINABILITY—A CREDIBILITY GAP?
Eugene T. Zak (Litton Industries, Inc., Guidance and Control Systems Div., Woodland Hills, Calif.)
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 182–191. 6 refs.
(SAE Paper-670627; A67-34661)

The nature and magnitude of differences between intrinsic and operational reliability and maintainability characteristics are presented. Relative supplier and user responsibility is cited. The difficulty in justifying increased reliability and maintainability is illustrated by means of hypothetical equipment selection, and direct mutual dependence of reliability and maintainability is demonstrated. A suggested approach to the reconciliation of intrinsic and operational values consists in recognition of mutual responsibilities of supplier and user, development of a clear conditional frame of reference for intrinsic claims, and application of more effective operational management controls. Data bank requirements for this approach are also established. Author (IAA)

Review: This paper is addressed to an important problem—the fact that operational reliability and maintainability characteristics of equipment are often grossly different from those quoted by the supplier. Illustrations of the nature and magnitude of the differences are presented. The author's suggested solutions: (a) that suppliers make only realistic and properly supported claims, and (b) that a general methodology for extrapolating from standard to other environments be developed, are fine in principle. However, as the author himself has indicated, the feasibility of implementing (a) and (b) under the current state-of-the-art is limited. The empirical "K-factor" method is one approach to (b), but it leaves much to be desired. Sorely needed is an adequate source of correlated operational reliability and maintainability data. Thus the paper does not solve the problem, nor was it intended to do so. Its merit lies in the fact that it calls attention to the problem and indicates, at least in general terms, what is needed in order to effect a solution. Getting the attention of enough of those who are in a position to help is a first requirement.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13655 ASQC 823
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
TO DEFINE THE BOUNDARIES OF INDIVIDUAL APPLICATION OF EXPONENTIAL AND NORMAL LAWS OF TIME DISTRIBUTION IN FAILURES OF ELEMENTS OF RADIO ELECTRONIC EQUIPMENT [K UTOCHENENIYU GRANITS RAZDEL'NOGO PRIMENENIYA EKSPONENTSIAL'NOGO I NORMAL'NOGO ZAKONOV RASPREDELENIYA VREMEN OTKAZOV ELEMENTOV RADIOELEKTRONNOY APPARATURY]
O. Ya. Gel'man 12 Dec. 1966 9 p refs Transl. into ENGLISH from Iev. Akad. Nauk Latv. SSR, Ser. Fiz. i Tekhn. Nauk (Riga), no. 4, 1964 p 119–123
(FTD-HT-66-524; TT-67-61115; AD-647719; N67-24489) CFSTI: HC $3.00/MF $0.65

The minimum of the generalized function of time distribution in the failures of radioelectronic equipment is studied with the aim of defining the boundary values of a parameter at which a separate application of the exponential and regular laws is possible for the evaluation of reliability. Author

Review: As an unedited rough draft translation, this is somewhat rougher than the average. Without the equations it would be very difficult to decipher. Apparently what the author has tried to do is assume that there are two statistically independent failure modes/mechanisms, one governed by the exponential law, the other by the Gaussian law. The three parameters of the two time values, above which the exponential distribution can be ignored, and below which the Gaussian distribution can be ignored. The results are given in terms of a graph and equations. All the mathematics was not checked, but it appears to be correct (although tedious). As a practical matter, the exact calculation is probably of little concern because one would probably just calculate the dividing line as the probability of failure where the two were roughly equal. The accuracy of the calculation need be no greater than the accuracy of the model which would be pretty poor in any event. Therefore, while the calculation by the author is interesting and probably contributes to the theoretical reliability literature, it is of little practical concern.

R68-13659 ASQC 824; 552; 553; 555
EFFICIENCY IN ESTIMATING SEMICONDUCTOR RELIABILITY.
Hugh J. McIntyre (Sylvania Electronic Systems, Western Div.).
Evaluation Engineering, vol. 6, Nov.–Dec. 1967, p. 50–53. 1 ref.

Reliability of semiconductors is estimated in their circuit applications by a technique which reduces the prediction preparation man-hours by 1/3 and permits technicians to do the bulk of the detailed work involved. Derived from MIL-HDBK-217A, the technique provides a maximum value in the performance of reliability predictions and tradeoffs on complex electronic equipment; and increases efficiency in performing reliability stress analyses and estimates on high reliability programs. Derating curves and nomographs are used to make the reliability estimates, and means of estimating thermal resistance are included. M.W.R.

Review: This paper is on a topic similar to that in [1], in that the tedious work apparently required in MIL-HDBK 217A is reduced by the use of equations or curves. This article is more extensive in providing means of estimating thermal resistance of various mountings. Not all the graphs were checked, but they appear to be accurate. Anyone who has to make a great many of these calculations should consider a technique such as this for reducing the tedium of the job. Such techniques are valuable in increasing reliability for two reasons: the less tedious a job is, the more likely it is to get done; and the time saved on such efforts can be spent profitably on reliability elsewhere.

Reference: [1] J. T. Henderson, "A Shortcut for Determining Semiconductor Failure Rates from MIL-HDBK 217A," *Industrial Quality Control,* vol. 24, Oct. 67, p. 207–208

R68-13676 ASQC 824; 851
RELIABILITY DEMONSTRATION OF CLUSTERED ENGINES.
D. K. Lloyd (TRW Systems Group, Redondo Beach, Calif.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 192–199.
(SAE Paper-670628; A67-34662)

Description of a statistical method for estimating and demonstrating the reliability of clustered liquid rocket engines from development, qualification, production, acceptance, and flight test results of varying durations. The method described is an extension of one previously developed for single engines. A worked example is given, and management control techniques for assuring data integrity are discussed. The mathematical derivation of the system reliability estimates is appended. Author (IAA)

Review: The method described in this paper is an extension of the one presented in the paper covered by R63-10960. Although the author's primary concern is with the statistical technique of estimation, the mathematical derivation of the reliability estimates appears in an appendix. A worked example is given in the body of the paper, and management control techniques for assuring data integrity are discussed. Thus the paper should be of interest and value to reliability engineers concerned with reliability demonstration programs. They may wish to ignore the appendix, which will be of interest mainly to statisticians.

R68-13677 ASQC 824; 844
THE USE OF ENTROPY IN RELIABILITY OF MEASUREMENTS.
John De Velis, (Merrimack College), and Haresh Shah (The Towne School of Civil and Mechanical Engineering, University of Pennsylvania.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 200–205. 12 refs.
(SAE Paper-670629)

Entropy concepts are used to determine the reliability of a given measurement, and attention is given to the degree of confidence of the resulting data. Properties of probabilistic entropy are introduced, and the entropy of a given one-dimensional Gaussian distribution is discussed in detail. The importance of entropy is considered in terms of its ability to measure the amount of information associated with a measurement, as well as to obtain a new physical interpretation of a process. M.W.R.

Review: This paper is difficult to read and understand unless one is thoroughly familiar with this particular treatment of the subject; in which case, of course, there is little point in bothering. The editorial standards are abominable; for example, (1) some symbols are completely omitted in several equations, (2) the arbitrary nature of one of the assumptions (namely, there is a minimum size region within which the probability density function is uniform) is not made clear, and (3) the statement "Utilizing the fact that equation 4 has been rigorously derived..." is without meaning unless we know what it was rigorously derived from. Virtually anything but a logical contradiction can be rigorously derived from something, but it may not have any applicability. It would seem also that some of the results depend heavily on the assumption of a Normal distribution for the actual observations. But there are some cases where it would appear that the distribution was anything but Normal. One difficulty with the reasoning in the text is that it apparently does not consider the case where the result of an experiment seems to contradict the a priori statements; presumably the experiment did contain some good information, but it is not clear how one would interpret these equations to show it. If the paper was intended to be tutorial, it clearly missed its mark. This is not to say that some of the ideas are not good, it is just that they are not well presented in this paper. Some of the references can give a clearer picture of various portions of the subject.

R68-13678 ASQC 821; 431

ON THE DISTRIBUTION AND PREDICTION OF EXCESS TIME.

Eginhard J. Muth (General Electric Co.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 206–213. 5 refs.
(SAE Paper-670630)

This paper considers a system whose components, upon failure, are repaired or replaced. Only two system states, the "operating" state and the "failed" state are distinguished. The time to failure and the time to repair of the system are assumed to be random variables with general distribution functions. A criterion of system worth is the random variable "excess time," denoted by B(t), and defined as the total time the system is down for t units of time spent in the operating state. The following questions are answered in this paper: (a) What is the distribution function of B(t)? (b) What are the moments of B(t) for large t? (c) What is the asymptotic behavior of B(t) for large t? (d) How can one make approximate probability statements about B(t)? It is shown that the gamma distribution is a suitable approximation for the conditional distribution of B(t), given that at least one failure has occurred; and that for t greater than 20, mean failure times the distribution of B(t) is practically normal. Author

Review: This is a mathematical paper concerned with the distribution of "excess time," defined as the total time the system is down for t units of operating time. While not all of the mathematical details were checked, a spot check indicates that the work is of good quality. Some typical situations in which this criterion of system worth is applicable are mentioned. The paper will be of value to theoreticians, particularly those with a background in renewal processes and an interest in their pertinence to reliability theory. The last section of the paper can be of value to the analyst in that it shows how the distribution of excess time can be approximated from information about the time to failure and the time to repair. A numerical example is given in that section. Several references to related and supporting work are cited.

R68-13687 ASQC 821

RELIABILITY OF PROTECTIVE DEVICES.

V. V. Malev

(Avtomatika i Telemekhanika, vol. 26, no. 9, Sept. 1965, p. 1606–1613.) *Automation and Remote Control,* vol. 26, Feb. 1966, p. 1558–1564. 1 ref. Translation.

Probability of preventing failure is determined for a system that includes an automatic protection device, which is designed to prevent failure. A system for which there is a stream of emergency conditions is considered, and it is assumed that there is no redundancy for the protective device, which can be either in serviceable or trouble condition. Maintenance of the protective device is also assumed, and mathematical models are presented to determine the reliability of the protective device and the behavior of the overall system. Both a general method for solving the problem and expressions for the mean time and the time dispersion of failure-free operation for selected cases are given. M.W.R.

Review: This is a theoretical paper and suffers somewhat from being translated by a person apparently not too familiar with the field. Not all the mathematics was checked but it appears to be competent. It will be of most use to theoreticians rather than to practicing design engineers. The criterion for comparing different procedures is the mean-time-to-failure and this is not necessarily the best criterion if the times under consideration are short compared to the mean. One of the reasons it is calculated and used here is that it is easy to do by the method of Laplace transforms.

R68-13688 ASQC 821; 882

RELIABILITY INDICATORS OF INDUSTRIAL AUTOMATIC EQUIPMENT.

A. I. Ressin

(Avtomatika i Telemekhanika, vol. 26, no. 7, July, 1965, p. 1274–1278.) *Automation and Remote Control,* vol. 26, Jan. 1966, p. 1256–1260. 2 refs. Translation.

Operational accuracy of automatic process control devices and the productivity and repair of equipment are considered in relation to reliability indicators for industrial automatic equipment. Mathematical models are derived for determining reliability of equipment, which is considered in either an operation or repair state; and a numerical example illustrates how reliability indicators can be calculated. M.W.R.

Review: In this paper there are two figures of merit for a process. The first is the average up-time (availability) and the second is the average rate of production of defectives. Poisson processes are assumed for failures, repairs, and production of defectives. Not all of the mathematics was checked but it appears to be competent. In the example, however, it is not clear where the values of the Poisson parameters as a function of age come from. They do not appear to have been given in the example nor to have been assumed in the previous derivation. This type of analysis could be applied to other things than industrial automatic equipment, for example, to the behavior of an inertial platform. The derivation in this paper is not difficult and it is very likely that some of the results appear in the American literature.

R68-13691 ASQC 824

MATHEMATICAL MODEL FOR PREDICTING GRADUAL FAILURES OF SYSTEM COMPONENTS.

V. O. Kurt-Umerov

(Avtomatika i Telemekhanika, vol. 27, no. 2, p. 142–146, Feb. 1966.) *Automation and Remote Control,* vol. 27, Feb. 1966, p. 318–323. 5 refs. Translation.

A mathematical model is proposed that plots changes in component parameters and, thereby, predicts gradual failures of these system components. Bases for the model are results accumulated on parameter changes that occur during operating conditions, and reliability of failure free component operation over specified time intervals can be determined. Details for constructing the mathematical model are given, and determining the scale of the model from past history is discussed. Reliability determinations are also considered in terms of predicted values of the permissible domain for the component parameters. M.W.R.

Review: This paper analyzes a very limited problem. It apparently does it well, although not all of the algebra was checked. It is a paper for theoreticians rather than practicing engineers because it will need too much interpretation in order to be applied. The paper presumes that there are small increments of time and small increments of performance (performance is considered a one-dimensional variable) and that at the end of each increment of time, the performance has either stayed the same or changed by the given amount. Each time consists of a separate Bernoulli trial and the probability is presumed to be estimated from measurements on the parameter taken at equal time intervals (not necessarily the same as the time increment above). With the estimates of the time increment, the performance increment, and the probability, the time taken for the performance variable to go out of bounds can be estimated. The author asserts that this technique was quite successful in improving the reliability of some vacuum tube control systems. This analysis does not seem to be of the type that has appeared in the American literature and so represents a minor contribution to the field of theoretical reliability.

R68-13692 ASQC 821
OPTIMUM, NONLINEAR, INERTIALESS CONVERSION OF SIGNALS FROM SEVERAL DEVICES, TAKING INTO ACCOUNT THEIR UNRELIABILITY IN OPERATION.
E. P. Gil'bo and I. B. Chelpanov
(Avtomatika i Telemekhania, vol. 27, no. 2, Feb. 1966, p. 70–75.)
Automation and Remote Control, vol. 27, Feb. 1966, p. 246–251. 3 refs. Translation.
(A66-25296)

Discussion of the optimum signal conversion in a signal-measuring unit which contains several unreliable measuring subunits, assuming that the random error distribution in the integral unit is known for both its normal operation and its failure. The nonlinear characteristic of a unit with minimized optimum error scattering is determined. In a three-component system, this characteristic ensures an averaging of reliable data and the rejection of unreliable data. The reliability threshold is determined by the a priori probability of instrumental breakdown. IAA

Review: This is an interesting little paper. It treats a special case in a way the Russians are apparently quite fond of and seems to do it reasonably well. Several approximations are made and these are acattered throughout the derivation so that it is not easy to tell the sum-total of approximations that have been made for the final answer. Not all the algebra was checked, but it appears to be competent with the exception of a few misprints. Basically what the authors have shown is a method for combining the outputs of three nominally alike devices in order to provide the "best" approximation of the proper output. It turns out that when all three devices are functioning reasonably well the average output is the one to take, that when one of the devices has failed it should be ignored and the average of the other two taken. In view of the authors' assumption of Normal distributions for the uncertainties introduced by the devices, it is likely that they need not have assumed statistical independence among all the random variables but need only have taken into account their linear correlations. The paper is a little difficult to follow due to roughness in translation. It will probably be more appealing to theoreticians than to practicing design engineers, but should be reworked by someone into a form suitable for design engineers.

R68-13693 ASQC 821; 831; 838; 882
CALCULATION OF RELIABILITY PARAMETERS FOR SYSTEMS WITH REPAIRABLE ELEMENTS.
Ye. P. Korchagina
(Radiotekhnika, vol. 21, Jan. 1966, p. 1–7) *Telecommunications and Radio Engineering, Part 2—Radio Engineering* vol. 21, Jan. 1966, p. 69–75. Translation.
(A66-37127)

Description of a method for determining time to failure and mean recovery time of a system with recoverable elements. Simple equations are derived to calculate these parameters for any number of working and redundant elements. Examples are given to demonstrate the application of the equations to the design of various circuits. IAA

Review: This is a theoretical paper and the mathematics appears to be competent although it was not all checked. The figures of merit used for the systems are availability, mean-time-to-failure, and mean-time-to-recovery. For redundant systems and times short compared to mean-time-to-failure, the failure rate is often a better figure of merit than mean-time-to-failure. The failure times and recovery times are assumed to be exponentially distributed. This paper will probably be of more use to theorists than to practicing design engineers. It will be of use especially to someone who is trying to make a compendium or survey of the various kinds of analyses available on this topic.

R68-13695 ASQC 821
DETERMINATION OF THE SURVIVAL PROBABILITY OF A LAUNCH VEHICLE RISING THROUGH A RANDOM WIND FIELD.
Ferdinand P. Beer and William C. Lennox (Lehigh University, Dept. of Mechanics, Bethlehem, Pa.).
Journal of Spacecraft and Rockets, vol. 3, Apr. 1966, p. 472–476. 6 refs.
(Grant NsG-466)
(A66-27870)

In the first part of the paper, the determination of the survival probability of the vehicle is based on the statistical analysis of the nonstationary random processes representing the responses of the various structural components of the vehicle. The probability that a given response will not exceed its critical value during the flight is expressed in terms of the joint probability density of the response and its derivative and, in the case of a normal distribution, in terms of functions of height representing, respectively, the ensemble average of the vehicle response and the variances and covariance of the response and its derivative. In the second part of the paper, it is shown that the survival probability of the vehicle may be determined from its dynamic characteristics and from the statistical characteristics of the wind field when the vehicle structure may be approximated by a linear model with time-dependent coefficients. Alternate expressions are obtained for the variances and covariance of the vehicle response and its derivative involving convolutions of either the impulse-response function of the vehicle and the covariance function of the wind field or of a height-dependent frequency-response function of the vehicle and the generalized power spectrum of the wind field. Author (IAA)

Review: This is a theoretical paper; not all of the mathematics was checked, but it appears to be of high quality. The approximations are clearly indicated and the development is straightforward. In order to follow the development one will need a considerable familiarity with probabilistic notation and some familiarity with the zero-crossing problem. The authors have assumed the simple stress-strength model for failure, viz., there is no cumulative damage. In a theoretical paper this is, of course, perfectly legitimate and it certainly does have application to some failure modes. It is interesting to note, however, that others have asserted that simple stress-strength failure is a rare type of structural failure in space vehicles. It is easy to suspect that whether one considers it rare or not depends on one's own particular field of interest; how well structural engineers have been doing their jobs is important too. The paper will be of more interest to theoreticians than to practicing design engineers, although eventually the results should be made available to design engineers in a form they can readily assimilate.

R68-13696 ASQC 824; 433; 822
Naval Postgraduate School, Monterey, Calif.
BAYESIAN METHODS AND RELIABILITY GROWTH
Harold J. Larson Mar. 1967 33 p refs
(TR/RP-78; AD-653460; N67-34019) CFSTI: HC $3.00/MF $0.65

A particular model is proposed for reliability growth and a prior distribution is assumed on the parameters. Various statements regarding the final reliability are then derived; a numerical example is included. TAB

Review: This is a mathematical paper concerning the derivation of the distribution of the achieved reliability conditional on the outcomes of the results of tests of N items. The Bayesian approach is introduced in the assignment of a priori distributions to the probabilities of observing a success (or failure) in any one of the possible failure modes of an item and to the probability of observing a success when the initial design is tested. A multivariate beta

density function is used as the a priori information. The assumptions are clearly stated and discussed as to their possible limitations. One of the critical assumptions is that once a failure mode has occurred in the tests it is either corrected and its probability of occurrence becomes 0, or it is unaltered and the probability remains the same. A numerical example is given to illustrate the technique. This paper can be of interest to those concerned with the application of reliability growth and of Bayesian statistics to reliability assessment.

R68-13697 ASQC 821; 431

RAND Corp., Santa Monica, Calif.

AN APPLICATION OF SPECTRAL THEORY AND A GENERALIZED BIRTH AND DEATH PROCESS TO A RELIABILITY PROBLEM

Alan J. Gross and Donald J. Persico May 1967 23 p refs
(Contract DA-49-129-ENG-522)
(P-3594; AD-652681; N67-32959) CFSTI: HC$3.00/MF$0.65

The authors consider a system of electrical generating units that must produce a constant amount of power for a specified length of time T regardless of the number of units operating at any time t, where 0 < or = t < or = T. Such a system is called a load-sharing system, because whenever a component fails the remaining operating components share equally among themselves the power increase required of the operating components in order to sustain the power output of the system. In addition to the N operating units we assume there are X units in an active standby capacity for the system. If an operating or on-line unit should fail and a standby unit is available, the standby unit is switched instantaneously (with a certain probability) into operation. We also assume there is a repair facility which is available for the system. Thus, whenever a unit fails, be it an operating or standby unit, the failed unit enters the repair facility. The authors develop and solve in this paper the system of differential equations which describes the operation of the system and whose solution enables us to calculate the reliability of the system at any point in time. TAB

Review: As indicated in a footnote, this paper is tutorial in nature and is thus suitable reading for a wide audience of reliability personnel. The presentation is quite clear except that the relationship to birth and death processes indicated in the title is never brought out. A system of linear first-order differential equations is derived and it is shown how the solution may be found in terms of the eigenvectors and eigenvalues of the matrix of infinitesimal transition probabilities.

R68-13698 ASQC 824

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

COMPARISON OF TWO METHODS OF OBTAINING CONFIDENCE INTERVALS FOR SYSTEM RELIABILITY

Sam C. Saunders (Claremont Men's Coll.) and J. M. Myhre (Claremont Men's Coll.) Nov. 1966 26 p refs Prepared in cooperation with Claremont Men's Coll. *Its* Math Note No. 477
(DI-82-0557; AD-647156; N67-31055) CFSTI: HC $3.00/MF $0.65

Some specific comparisons are made in the note between the use of the asymptotic Chi-square distribution of the likelihood ratio and the asymptotic normality of the maximum likelihood estimates to obtain confidence interval for reliabilities of arbitrary systems when only failure data on the components is known. In all the comparisons made, using moderate samples and systems of average complexity, the asymptotic Chi-square appears to give much more accurate confidence intervals. Although the asymptotic Chi-square method requires machine computation for all but the simplest systems while the asymptotic normal method can be done easily by desk calculator, these examples would indicate the Chi-square method would be superior in most practical instances. Author (TAB)

Review: In this report comparisons are made between two asymptotic methods of obtaining confidence intervals for reliability. The two methods were presented in the papers covered by R65-12235 and R67-13031. The comparison is made for "small" and "moderate" sample sizes. The exposition is clear and precise. Several references to earlier work in this area are given.

R68-13699 ASQC 824; 424

National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

ESTIMATION OF PARAMETERS IN COMPOUND WEIBULL DISTRIBUTIONS

Lee W. Falls 30 Mar. 1966 43 p refs
(NASA-TM-X-53422; N67-11352) CFSTI: HC$3.00/MF$0.65

The two-parameter Weibull distribution has been recognized as a useful model for survival populations associated with reliability studies and life testing experiments. In the analysis of atmospheric data, the distributions encountered are often a result of combining two or more component distributions. These compound distributions are consequently of interest to aerospace scientists. Presented is a method for estimation of the parameters of a compound Weibull distribution with two shape parameters, two scale parameters, and a proportionality factor. The most general case of estimation will be considered in addition to a number of special cases that may be of practical value. Author

Review: This report will be of interest to many practical reliability research workers. The title is somewhat unfortunate in that the terminology "mixed" rather than "compound" is fairly standard. The reader might also be cautioned to read the author's conclusions before reading the middle of the report. The method of moments is used (involving up to sixth-order moments) and, as the author points out in the conclusions (not before), this method is in some cases inefficient and large sample sizes will be necessary to get "good" estimates. However, the numerical example given has a sample size of 2000 and excellent results are obtained in this case.

R68-13700 ASQC 824

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

A MULTIVARIATE NOTION OF ASSOCIATION FOR GENERAL RANDOM VARIABLES

J. D. Esary, Frank Proschan, and D. W. Walkup Repr. in *The Annals of Math. Statistics,* v. 38, no. 5, Oct. 1967 Oct. 1966 15 p refs *Its* Math Note No. 490
(DI-82-0578; AD-643976; N67-20602) CFSTI: HC $3.00/MF $0.65

In a previous paper (a multivariate notion of association, with a reliability application) random variables T1, T2 ....., Tn were defined to be associated if each pair of non-decreasing functions F(T1, T2, ..-..Tn), G(T1, T2, ..., Tn) have a non-negative covariance. The properties of this definition were studied in the case that T1, T2, ..., Tn are finitely discrete, and a sample application to reliability theory was discussed. In the present paper several equivalent definitions of the same notion of association for unrestricted T1, T2, ..., Tn are treated. The properties previously obtained, i.e. that association is preserved under the operations of extracting subsets, pooling independent sets, and forming sets of non-decreasing functions, are shown to hold in general. In addition, association is shown to be preserved under limits in distribution. Some additional applications of association are discussed, e.g. previously published results of A. W. Kimball and H. Robbins are obtained. Author (TAB)

Review: This report presents a substantial generalization of recent work in this area by the authors. Several applications to partial sums of random variables, order statistics, a multivariate exponential distribution, and the analysis of variance are given. Closely related papers are those covered by R67-12969, R68-13554, and R68-13650.

R68-13704 ASQC 824; 831
MALFUNCTION DETECTION SYSTEM FOR ADVANCED SPACECRAFT.
K. F. McSweeney (Grumman Aircraft Engineering Corp., Space Advanced Systems Group, Bethpage, N. Y.).
IEEE Transactions on Aerospace and Electronic Systems, vol. AES-2, Jan. 1966, p. 27–35. 9 refs.
(A66-22043)

A design approach for a Malfunction Detection System (MDS) to be used on board a manned spacecraft is considered. This design is directed toward orbiting laboratory type vehicles, in which man will be subjected to hostile environments for extended periods of time. The prime purpose of the MDS will be to monitor and evaluate critical signals and display out-of-tolerance conditions. This paper initially discusses a mathematical model approach to a monitoring-system design. Another topic covered is the feasibility of using some value less than the specified tolerance as a signal "test" limit. Finally, various design decisions and trade-offs involved in choosing a monitoring subsystem configuration are discussed, and the conclusion is that the approach is feasible and could be expanded to include other capabilities. Author (IAA)

Review: This paper discusses a design *approach* for the malfunction detection system and thus tends to be more qualitative in the discussion of system aspects than would a paper discussing a specific system design. The introductory comments about mathematical models are good. The discussions of probabilities and system accuracies are poor. For example: (1) The Normal distribution is given incorrectly. (2) The limiting statements on page 28 are incorrect. (3) Fig. 1, which shows some probability density functions, is misleading and the areas shown for describing some of the probabilities are not correct. (4) The discussion of test equipment accuracy is not clear. (5) There is apparently a misprint in connection with the term $n\sigma$. The author may mean $Pn\sigma$ which he is apparently using in place of $P_{n\sigma}$. Why this confidence is introduced is not clear since the true values of the distribution are presumably known. (6) The initial equations on page 30 which define E_i are not correct. This kind of error is easy to fall into unless one writes down the event "equation" first; then one should take probabilities and expand the statement according to the applicable rules. (7) The equation for B is not obvious in the first place and in the second place its value is identical to $1/2T_1$ from Fig. 1 (since T_1 is apparently the mean of the distribution of X_2 and the integral of any Gaussian distribution from minus infinity to its mean is one-half). The expansion of B into the difference of absolute values is not obvious. The rest of the probability discussion was not evaluated due to the poor start. In discussing the method of checkout the statement is made, "...it is apparent that the operating life of the device is being shortened due to testing." One has to be careful in interpreting a statement like that because if the test shows that the device is working, time can be reset to zero for that device at that time. If it is found to be not working, then it was wise to have tested it. This is a consequence of the exponential distribution wherein the hazard rate of the device is a constant so long as the device does, in fact, continue to operate. The final comparison of various techniques for the system is qualitative and relies on reasoning performed outside the paper. It is certainly a reasonable discussion.

83 DESIGN

R68-13660 ASQC 830; 711; 844
PREVENTING MECHANICAL POWER-TRAIN FAILURE BY DESIGNING IN WEAR-MONITORING SYSTEMS.
D. W. Botstiber (Technical Development Co., Glenolden, Pa.).
Machine Design, Oct. 26, 1967, p. 170–176.

Early detection of wear on parts is considered in terms of preventing mechanical power-train failures that suddenly occur due to gradual wear of parts. Since changes in noise, vibration, and temperature resulting from part wear require the measurement of signals emitted only during operation, the system must be monitored during operation and provisions must be made to record these signals during equipment rest periods. Built-in systems that can monitor such operational changes and trace wear progress are discussed. Lubricant wear signals are described, including chemical changes, visual changes, oil viscosity, and evaporation losses; and methods for monitoring wear particles in oil are included. Methods of detection include filtering; sampling by spectrographic analysis, electrical resistance testing, and centrifuging; and magnetic separation. Alarm systems are discussed, including screen-type oil monitors with overflow, an oil monitor with self-closing chip detector and instrumentation, and a chip-detector probing circuit. M.W.R.

Review: The use of pre-failure indications can be an important part of high reliability for both electrical and mechanical systems. (Only mechanical systems are covered in the present article.) When a pre-indication of failure is shown, the equipment can then be removed from service at a convenient time and repaired rather than having the equipment fail during attempted use. This paper summarizes several of the systems for monitoring mechanical wear (which in this case would include spalling) and concentrates particularly on methods for monitoring the lubricant (presumed to be an oil). The paper is tutorial in nature, is fairly short, and is well written for its purpose.

R68-13679 ASQC 838; 824
A PRACTICAL CIRCUIT FOR INTEGRAL MAJORITY-VOTING LOGIC ELEMENTS.
Robert W. Stoffel and John L. Donaldson (Martin Marietta Corp., Martin Co., Denver, Colo.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 236–244. 4 refs.
(SAE Paper-670632; A67-34664)

As an introduction, the paper shows that for spacecraft systems to be designed for the next generation of scientific missions, the system complexity and long life requirements produce reliability criteria which cannot be met by either current satellite logic circuitry or application of redundant sets of such circuitry. The paper then describes a circuit composed of available integrated circuits along with a passive voter circuit and providing majority voting at the logic element level. This circuit is analyzed both from reliability and performance standpoints to show that approximately two to three orders of magnitude improvement in reliability without any significant degradation in performance is realizable. Author (IAA)

Review: This paper deals with majority voting logic applied at the level of the logic circuit. In this case a NAND circuit is used to illustrate the procedure and to provide calculations which demonstrate the vast superiority of this method of redundancy over a nonredundant computer and over one with simple redundancy at the output. There are a few difficulties with the paper. Not all of them are insurmountable, however. The following are examples. (1) The statement "It is well known that redundancy applied at the lowest possible level maximizes the reliability improvement to be gained" is true only when it is assumed that all other things are equal (which is rarely the case) and that only a given class of redundancy types is being considered. It is also true only as long as all failure events are statistically independent. (2) The algebraic expressions for probability of failure are incorrect; although they give the correct approximation for small probabilities. There are several possible explanations: (a) There was difficulty in deciding which portions of the system have a constant hazard rate. It is reasonable for the reader to assume that the parts for which λ's are given are the ones for which the constant hazard rate is assumed (any other guess runs into severe difficulties). (b) When the probability of one failure is calculated, it is not clear whether there is the additional implied assumption "and no others." It does make a difference, although the text is incorrect in either event. (c) If the authors assumed that when the equipment fails, all degradation stops, then there are serious troubles with the statistical independence assumption. (d) If the time order of events must be considered, then the events are probably not statistically independent; again serious difficulties arise. If we make the reasonable assumption in (a) and presume that no complications were intended as in (c) and (d), then the probability, P, of a dual failure (regardless of other failures) is $P_{ab} = [1 - \exp(-\lambda_a t)][1 - \exp(-\lambda_b t)]$; and the probability of a dual failure (and no others) is $P'_{ab} = [\exp(\lambda_a t) - 1]\ [\exp(\lambda_b t) - 1]\ \exp(-t\Sigma\lambda)$. (3) Some of the hazard rate calculations show four significant figures; while the arithmetic may well give this many, an accuracy is implied at least 100 times as great as exists. The only criterion given for the goodness of the redundant methods is probability of failure. Other measures of performance such as noise immunity are not quantitatively considered. The paper is a good analysis of the comparison of specific systems according to specific criteria. Extrapolation beyond either of the restrictions is not wise.

R68-13681 ASQC 836; 844

TECHNIQUE FOR RELIABILITY CIRCUIT DESIGN REVIEW IN SPACE ELECTRONICS.

P. J. Franciscovich (International Business Machines Corp., Federal Systems Div., Gaithersburg, Md.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 261–271. 3 refs.

(SAE Paper-670634; A67-34666)

Discussion of a reliability circuit-design review with emphasis placed on what should be reviewed and the review techniques employed. The basic circuit-design-review prerequisites, component parts, and their ratings are outlined. Such review items as worst-case circuit performance, component performance, component applications, failure-mode analysis, noise rejection, electrical stress, and the determination of component temperatures are considered. Many examples are included to illustrate how each item is accomplished. IAA

Review: This paper will be best understood and appreciated by those with some experience in design reviews. The novice is likely to find it confusing because of the organization and lack of distinguishing between important and trivial details. An example of a trivial detail is using half a page to show how to calculate the parameters of a straight line on semilog paper. There is also an implication that this equation for the line will be more exact than tables of diode curve approximations. The chances are very good that the accuracy of the calculated value as compared to the actual value for a diode will be reasonably independent of which of the three methods (the diode curve, the equation, or tables) is used. The suggestions the author makes for design reviews are good ones. Several methods have recently appeared in the literature for easing the chore of calculating allowed power dissipation for single junction devices. (See, for example, the paper covered by R68-13634 and [1].)

Reference: [1] Hugh J. McIntyre, "Efficiency in Estimating Semiconductor Reliability," *Evaluation Engineering*, vol. 6, Nov/Dec 67, p. 50–53

R68-13684 ASQC 833; 816

STANDARDIZED TECHNIQUES FOR THE SELECTION OF HI-REL MICROELECTRONICS.

Eugene Slaughter (General Precision, Inc., Kearfott Products Div.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 351–355.

(SAE Paper-670643)

Standardization of military and/or industrial specifications is urged as the means of improving product quality; and coordinating activities are suggested for device testing, communication between user and manufacturer, and corrective action programs. Experiences related to integrated circuits are reported, and the assessment of vendor capability is discussed. The use of a specification control drawing (SCD) and its means of assuring quality of microelectronic devices are noted; and the five areas considered in the SCD are physical characteristics, electrical characteristics, environmental conditions, power conditioning/screening procedures, and overall quality assurance. Such SCDs have been developed by industry because the Department of Defense has not set standards with regard to microelectronic devices. M.W.R.

Review: This paper contains much good material, and the plea for some kinds of standardization in specifications for microelectronic devices is a good one. This paper is not for the novice in microelectronics since he will be overwhelmed, nor is it completely applicable to the purchasers of small quantities of microelectronics since they are largely at the mercy of the suppliers anyway, especially in today's markets. Vendor surveys can be a problem to vendors inasmuch as the major vendors have to spend a lot of their time just being surveyed rather than doing their jobs. One approach which is not mentioned in this paper explicitly is to pick a high volume microcircuit, purchase it off the shelf from the supplier, and then run it through screening tests in-house. Some people claim much better results this way than by ordering specials. As is the case with most papers which describe programs, the paper describes what the author would like a program to be. It does not go into details of the many exceptions that must be made in day-to-day life, and has no concern about the fact that programs do not execute themselves, but are carried out by people—and are carried out only as well as the people decide to do it.

R68-13685 ASQC 833; 770; 815

RELIABILITY—FROM FACTORY TO TARGET.

W. L. Hadley (Martin Marietta Corp., Friendship International Airport, Md.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 356–363. 9 refs.
(SAE Paper-670644; A67-34672)

Discussion of the reliability-prediction prospects for electronics products, considering their factor-to-target progress and significant reliability factors involved. These include logic selection, parts selection, application rules, piece parts testing, module level and assembly level testing, system level testing, process and packaging, and nonoperating storage. The lasting effect of the practices adopted in design, manufacture, test, and operational use on the survival of electronics products is emphasized. Technological effects are urged to close the gap between today's reliability prediction techniques and those needed for complete control of system reliability. IAA

Review: This paper is concerned with the field of missile electronics rather than the discipline of reliability in general. It does achieve its purpose in discussing additional work to close the gap between today's prediction techniques and those that are needed for complete control of system reliability. The points made are generally good ones and the problems which are raised are really there. A minor reverse comment is the giving of failure rates to as many as four significant figures just to have the decimal points come out right; as long as no one thinks they are really that accurate there is probably no harm done. Design problems are discussed to some extent. Techniques for assuring good design such as design reviews are not mentioned; nor is a production review. Integrated circuits are asserted to have a much lower failure rate than the equivalent discrete components. This should be qualified with a statement that they can have it, if they are appropriately selected and screened. It is not uncommon to hear a consumer say that perhaps 10% of the integrated circuits he buys are grossly defective—some people would probably put the figure much higher. All in all the paper does provide a reasonably practical outlook.

R68-13689 ASQC 830; 782
HOLD DOWN TURBINE OPERATING COST BY LENGTHENING PART LIFE.
John C. Pirtle (General Electric Co., Flight Propulsion Div., Cincinnati, Ohio).
SAE Journal, Mar., 1966, p. 60–62. 1 ref.

Temperatures of materials used in turbine engines must be held down to a tolerable level if component lifetimes are to be lengthened; and air cooling, while retaining the benefit of high cycle temperature, is suggested as a practical means of increasing component life. Relative increase in cyclic life of a turbine disk attained through air cooling is illustrated; and it is noted that removal of material can increase the cyclical life of compressor spacers, with deep scallop configuration proving far more effective than adding material to increase edge thickness. Cooling of stator parts is discussed, and some test results are included. M.W.R.

Review: Even though the title of the paper implies a concern with cost, the paper itself equates low cost to long life and proceeds to show how the high temperature portions of a jet engine can be designed so that long life will be achieved. Stress analysis of the parts including stresses due to temperature gradients has apparently been programmed for a computer. This has two advantages: (1) it is more likely to be performed, and (2) the details of the analysis can be somewhat more complex than would be feasible if the analysis were to be performed by hand. The main emphasis of the paper is on how proper cooling of the blades can reduce the stresses and thus improve the low-cycle fatigue characteristics. There are two examples of the kind which stress analysts are always proud to show, viz., those in which stresses were reduced by *removing* material rather than by adding it. The paper is written from a very optimistic point of view—the techniques described here are undoubtedly good, but a comparison with the natural phenomena in Yellowstone National Park is apt. The phenomena are wonderful to behold, but not nearly so wonderful as the guidebook describes them to be.

R68-13690 ASQC 830; 782
RELIABILITY. (PANEL DISCUSSION: SOME ELECTRICAL/ELECTRONIC AREAS REQUIRING EMPHASIS IN PREPARATION FOR FUTURE SPACE PROGRAMS).
D. C. Regan (NASA Manned Spacecraft Center, Instrumentation Reliability Section, Houston, Tex.).
(1965 Aerospace Conference, Houston, Tex., June 23, 1965, Panel Discussion.) IEEE Transactions on Aerospace and Electronic Systems, vol. AES-2, no. 1, Jan. 1966, p. 131–136.

Electrical and electronic areas that require emphasis in preparing for future space programs are discussed in relation to lunar operations, manned or unmanned orbital operations, and interplanetary probes. The need for improvement in reliability prediction methods is stressed because of the high reliability requirements of long duration missions; as are the severe weight, power, and space limitations imposed on equipment design that tend to produce predicted reliabilities which are too low to meet mission requirements. It is noted that all of existing prediction methods are based on sampling methods, and that what the space industry really needs is a set of failure rates that are valid statistics for predicting space hardware reliability as well as a means of determining modes of failures for each component. Good management of programs is stressed as a means of motivating employees to carry out effective programs, and mention is made of the NASA training and certification programs that have produced positive results. M.W.R.

Review: This paper is the report of a panel discussion and is superior to many other such reports in that it includes not only the prepared talks by the panelists but the question and answer session. There were five panelists, one each in the areas of life support, communication, navigation, system integration, and reliability; only the reliability portion is being reviewed here. The first thing to note is that the problem areas mentioned by the panelist are still with us. They are likely to stay with us for a long time because our goals progress as fast as our ability to achieve them. Thus engineers are virtually always working somewhere near the state-of-the-art on the space program. The comments on reliability prediction and on environments are good. Two points need further comment. (1) "Failure under stress is usually not instantaneous but is analogous to an energy function rather than a power variable." This statement helps to explain why some people have referred to "the energy required to cause failure" when the criterion is clearly not that of energy. What they were apparently driving at is that the material has a certain endurance which is consumed as a function of time or that the total amount of damage being done is a time integral . The panelist has stated his concept well since he used the term *analogy;* others have been less clear. The simple stress-strength model of failure, however, does apply to some failure modes of some items. (2) The term "inherent reliability." This is an unfortunate, although ubiquitous term. In this paper it is better defined than often is done, but still is an extremely elusive concept. Basically what people usually mean by inherent reliability is the reliability that would be calculated from experience if certain kinds of failures are omitted, viz., those which a designer could blame on anyone other than himself. It is easy to see that if a designer is alert, imaginative, and aggressive, the inherent reliability can be extremely close to one. It is also easy to see, when defined in this form, that the term does not have much utility. The discussion on quality of hardware repeats two statements

which need to be challenged. The first is a truism that, "Nearly every failure can ultimately be traced back to actions of personnel either by commission or omission." Unless no human being has ever had anything to do with the item beginning with its concept, following through design, raw material, production, installation, and use, it is clear that people are responsible for what happens. The question is, how stupid or gross was the human action? It can also be said that every failure is a material failure. What these kinds of statements really need to show is where it is most useful to assign responsibility for correcting this failure. The other challengeable statement is the "...classic axiom that quality must be built into the product; it cannot be inspected into the product." The statement is true in one sense that there must be some parts of good quality around. But it is also true that defects can be inspected out of a product, as complex as space hardware. In fact this is what check-out and countdown are all about. In the question period the panelist was not expansive about a question on demonstration of reliability (technically he answered it because he was only asked to comment on what he thought of it), where a demonstration is expensive and time-consuming. It would have been appropriate in this response to mention the need for ways of using prior information. The statement, "You reduce the risk as much as is humanly possible..." is not really true. You do this within the constraints imposed upon you from above and, like it or not, there *are* calendar-time and cost restraints. (It is interesting, however, to compare the tremendous effort to insure survival of the astronauts with two other things: (1) Expeditions of explorers on the oceans beginning, say, around the fifteenth century and with the explorers in this country who originally opened the uncharted areas of the West. (2) The care taken to protect the ordinary person whose vehicle is not a space one, but is his manned automobile, and whose mission is not space exploration but to get to work and back.) Another question was on the relative value of redundancy versus extreme care that the primary system will work. No mention in the answer was made about nonoperating degradation nor of active redundancy such as majority voting or parallel systems. In the panelist's reply to a request for elucidation on his statements that," . . . the safety margin should be built into the hardware and not into the environmental stress levels," the answer is not too clear. In the first part of the response he deals with the very good point that trade-offs have to be made, e.g., if the environmental level is set arbitrarily high, the part chosen may have poor properties for the balance of the mission. Thus there is some kind of optimum selection of environmental levels where the safety or reliability is optimized. The latter part of the statement deals with the fact that with the large boosters now available weight is no longer a real problem and people should be thinking in terms of large experiments rather than small ones. The above discussions of some of the panelist's points are not meant to imply that the paper is not worth reading. It certainly is. They are meant to show that one should read the paper critically to get the most from it.

R68-13703 ASQC 830

EFFECTS OF RELIABILITY CONSIDERATIONS ON THE DESIGN OF ELECTRIC THRUSTER ARRAYS.

J. H. Molitor, K. R. Pinckney, and R. L. Seliger (Hughes Aircraft Co., Research Laboratories, Ion Propulsion Dept., Malibu, Calif.). *(American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N. Y., Jan. 25–27, 1965, Paper 65–68.) Journal of Spacecraft and Rockets,* vol. 3, Apr. 1966, p. 554–560.

(AIAA Paper-65-68; A66-27883)

Analysis of power-conditioning and ion-thruster system reliabilities for ion propulsion engines. The characteristics and power supply requirements for surface-contact and electron-bombardment ion engines are reviewed, and the reliability and specific weights of power conditioners for high power (250 kw) propulsion systems are evaluated. A brief review and extension of general reliability theory are presented, and reliability optimization considerations are applied to the power conditioning circuitry and to thrustor grouping. Although the specific examples discussed are typical of high-power nuclear–electric systems employing cesium surface-contact and mercury electron-bombardment ion engines, the reliability considerations are general, and are equally applicable to the lower-power solar–electric propulsion systems. IAA

Review: This paper applies the simple reliability estimation procedures to the design of electric thrusters. It shows clearly that using only the more conventional parameters, e.g., weight and performance, is not enough to solve this problem—that reliability considerations are essential. While the availability of new and improved equipment will change the details of some of the calculations, the principles involved will remain the same. It should be noted, however, that the authors have assumed a zero failure rate for modules in the stand-by condition. While the failure rate in the stand-by condition may be negligible, it is now generally considered that this assumption should not be made blithely, but that some limits should be placed on the nonoperating failure rate. This paper is directed toward a practicing design engineer involved in this field. It does not attempt to advance the theory.

84 METHODS OF RELIABILITY ANALYSIS

R68-13658 ASQC 844; 771

INVESTIGATION AND REDUCTION OF DIODE STRESS FAILURES.

A. Alan Porter (North American Rockwell Corp., Rocketdyne Div., Canoga Park, Calif.) and Bernard Ostle (Florida Technological University, College of Natural Sciences, Orlando, Fla.).

Evaluation Engineering, vol. 6, Nov.–Dec. 1967, p. 38–40, 42.

(A68-12743)

Discussion of a statistical approach to an engineering program as it functioned in the investigation of the effects, on the incidence of diode stress failures, of various methods of shielding, mounting, and coating the diodes. For test purposes the diodes were mounted on special printed-circuit boards, each diode being subjected to the following series of events: (1) shielding and mounting; (2) temperature cycling (+140 to −250°F); (3) coating; and (4) temperature cycling as in (2). Before and after each of these four events the diodes were checked visually and electrically. In addition, the diodes were monitored electrically during temperature cycling. Upon completion of the test series, the diodes were examined with regard to shorting elimination. The variable of interest in the investigation is taken to be the success or failure of a diode to complete the test series, a failure being defined as "extreme degradation of the diode characteristics." The descriptions of the planning and analysis efforts involved are typical of the statistician's role in many engineering programs. IAA

Review: A reasonably detailed description of a test program for diodes is given in this paper. It will be of interest to those concerned with the design of similar programs. A strong point is made regarding the statistician's contribution to the program. However, it appears that the statistician is acting in the capacity of an engineer who knows what he is doing rather than someone who knows much about statistics. It is not obvious why the statistician would be of any more help than would a good engineer on a program that involves more engineering than statistics. Perhaps the best contribution that the statistician makes when called in on such a problem is to keep complicated statistics out of it (which is what this one did).

R68-13661 ASQC 844; 830

MAJOR CAUSES OF EQUIPMENT UNRELIABILITY.

J. Paterson (British Aircraft Corp. (Operating), Ltd., Guided Weapons Div., Stevenage, Herts., England).

(Letchworth College of Technology and Institution of Electronic and Radio Engineers, Conference on Reliability and Environmental Testing of Electronic Components and Equipment, Letchworth College of Technology, Letchworth, Herts., England, May 3, 1967, Paper.) *Radio and Electronic Engineer*, vol. 34, Oct. 1967, p. 247–250.

(A67-42479)

Discussion of those areas in electronic design and construction which contribute to the unreliability and failure of electrical and electronic components in guided-weapon systems. Prime causes of electromechanical-component failure are judged to be the lack of experience and tolerance variations in component and equipment manufacture. A combination of these weaknesses with the unusual equipment use presents a further reason for the high failure rates. Various causes of failure in electronic modules are analyzed, including packaging problems and environmental conditions. It is suggested that improved customer–manufacturer relations and standardization of new types of components may prove to be a solution to the problem. Particular attention is devoted to the necessary evaluation of detail in component manufacture. IAA

Review: One of the main themes of this paper is that a significant cause of equipment unreliability is the silly mistakes that people make when designing and building it. These mistakes are the ones that are difficult to catch except by attention to the small details. Indeed the author suggests more attention to detail as a cure for most of these causes, especially the unglamorous kind associated with such things as screw lengths being correct and wiring not being routed past sharp metal. He further suggests that complexity breeds unreliability because of the increased detail which must be looked after and which rarely gets the necessary attention. By and large the author's points are very good. The use of computers in design may help the problem because they never get tired of paying attention to the details they are told to look at. A large portion of the general reliability effort should be (and is) spent in automating this attention to detail.

R68-13662 ASQC 844

TRANSIENT JUNCTION TEMPERATURE RISE AND FAILURE ENERGY OF TRANSISTORS.

Keiji Takagi and Kunio Mano (Tohoku University, Faculty of Engineering, Sendai, Japan).

Electronics and Communications in Japan, vol. 48, Oct. 1965, p. 33–41. 13 refs.

(A67-11235)

Proposal of a method of using forward-potential sampling of a transient junction to obtain the junction temperature rise. The transient thermal resistance of the transistor is also obtained by this technique. It is shown that when the applied electrical power is constant, the failure energy can be directly estimated from the thermal resistance thus obtained. The results of investigations of the failure of transistors in inductively loaded switch circuits are discussed and compared with the secondary breakdown phenomenon. The conditions for secondary breakdown are studied in relation to the transient thermal resistance, and it is determined that they comprise a type of runaway situation. IAA

Review: The authors have apparently developed new methods for measuring junction temperature and for calculating second breakdown thresholds. The latter calculation is based on measured values of thermal resistance as determined by the junction temperature measurements. In spite of the date of this publication (1965), the author's methods do not seem to be widely known. For example, no mention of this work appears in a recent (1967) second breakdown review by Schafft [1]. Part of the reason for widespread ignorance of the authors' work may rest with the unsatisfactory exposition of it in this publication. From this account alone the reader has considerable difficulty in understanding what the authors have done. Part of the reason is no doubt the fact that the authors published originally in Japanese and have been translated by the IEEE into English. However, another part of the problem seems to be inadequate detail. The reader is left with too many unanswered questions. Researchers specializing in second breakdown may well want to invest the labor required to assess more fully the merit of the work, for the methods are unique to these authors and seem powerful. For most readers, however, the paper will probably be an unprofitable expenditure of time.

Reference: [1] Harry A. Schafft, "Second Breakdown—A Comprehensive Review," Proc. IEEE, vol. 55, Aug 67, pp. 1272–1288

R68-13664 ASQC 844; 770

ENHANCING THE OPERATIONAL READINESS OF AVIONIC SYSTEMS.

Frank B. De Armond (North American Aviation, Inc., Autonetics Div., Anaheim, Calif.).

In: NAECON/66; Proceedings of the Annual National Aerospace Electronics Conference, 18th, Dayton, Ohio, May 16–18, 1966. Technical Papers. Conference sponsored by the Dayton Section of the Institute of Electrical and Electronics Engineers. Dayton, Ohio, Institute of Electrical and Electronics Engineers, 1966, p. 39–43.

(A66-35504)

Discussion of the applicability of built-in tests and periodic testing at the field shop level to alleviate problem areas in avionic systems. System-level tests are performed to determine whether or not an avionic system is capable of performing its intended mission. Five basic concepts for built-in test systems are presented. The field-shop tests employ multiple-test station systems which operate a number of independent test stations under time-shared central control and central processing units to control each test station. IAA

Review This paper is largely tutorial in nature. It explains the purposes of built-in testing, what it can do for you and why it should do it. It is a short paper and does not go into detail on any of the points but is quite suitable for introducing someone to the concepts involved. For large systems, built-in testing is a good way of improving reliability.

R68-13665 ASQC 844

Canadian Marconi Co., Montreal (Quebec). Components and Reliability Section.

FAILURE MODES AND EFFECTS ANALYSIS

T. David Kiang 12 p refs Presented at the 21st Ann. Tech. Conf., ASQC, Chicago, 31 May–2 Jun. 1967

Objectives, requirements, and computer utilization are discussed for Failure Modes and Effects Analysis (FMEA), which determines the effect of various component failures on system performance. A general procedure for conducting FMEA is outlined at the system, functional, and piece part levels; and method of approach, techniques, and tools are delineated for each of these analysis levels. M.W.R.

Review: The author's stated purpose was to explore the areas included in a Failure Modes and Effects Analysis (FM&EA). This purpose is accomplished quite well in a clear and concise presentation. Ten references are cited in which more detail may be found. Those interested in a description of the general approach to this type of activity will find the paper useful. FM&EA is generally very worthwhile. Specifics of implementation will, of course, depend on the nature and complexity of the equipment involved.

R68-13667 ASQC 844; 782
PREDICTING ENVIRONMENTAL INTERACTION.
Gerald Coren (Fairchild Hiller Corp., Republic Aviation Div., Farmingdale, N. Y.), William Cotliar, and David Conroe.
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, 1967, p. 12–19.
(SAE Paper-670611; A67-34650)

Outline of the elements required in a study of the effects of environmental interactions. A technique for quantitatively predicting the effects of combined environments on components is described, and the results of the application of this technique to test data obtained under controlled conditions are cited. A statistical analysis is made of the data obtained, after equalizing the synergistic effects with respect to exposure time and the number of environmental encounters. IAA

Review: This paper deals with an important topic and has some good information in it. It might better have been entitled "*Measuring* environmental interaction" since the paper does no predicting. The use of the term probability to describe the authors' concepts is poor because some of the quantities (which are allegedly probabilities) turn out to be negative. Negative probabilities, of course, are "illegal." The authors make no attempt to justify the form of their synergistic correction: an additive one. One might wonder why a multiplicative one was not better. In fact, eventually the paper derives a multiplicative one in terms of a percentage increase. Presumably the correction is not applicable, in any of the ways in which it is described, if any of the stress levels are changed. Under the discussion of mechanism of failure the lead sentence is, "One theory presented to explain the mechanism of part failure is based upon the following assumption: ..." But later in the paper the discussion proceeds as if these assumptions were demonstrated facts. The third assumption; viz., the effect of sequential environments is independent of the order of application, is not true in general. For example, vibration (first stress) could cause a crack which would allow moisture (second stress) to penetrate a case; whereas, if they were done in the reverse order, there would be no moisture penetration. *Care should be used in generalizing the* results of the analysis of variance on the synergistic effects, since the data limitation was severe and since other hypotheses might have had different outcomes. Many environmental engineers will question seriously the statement that the synergistic effects are negative, although there can be little doubt that such is the case *for the data used by the authors.* All in all, the paper should be read very carefully to be sure that one has analyzed just what it is the authors did say and that it was a legitimate inference from their data.

R68-13669 ASQC 844; 824
SAFETY ANALYSIS OF STATICALLY INDETERMINATE TRUSSES.
J. T. P. Yao and H. Y. Yeh (University of New Mexico, Department of Civil Engineering).
In: Annals of Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 54–62. 5 refs.
(SAE Paper-670615)

Effects of stress redistribution that are caused by the failure of certain redundant members in an m-member statically plane truss are investigated in terms of overall structural system reliability and safety. The system has random resistance and is subjected to random loads. Numerical results indicate that the failure of one member of a statically indeterminate structure does not always imply the failure of the entire structure, and that statically indeterminate structures may have greater probabilities of complete survival than statically determinate structures with the same volume. From a reliability viewpoint, the type of statically indeterminate structures considered should be designed so that each component has an equal cross-sectional area. Applicability of the analysis technique to the solution of aerospace-related problems is shown by calculations for a three-dimensional parachute-like structure, for which the effect of the number of members on probabilities of complete survival becomes less pronounced as the volume of the structure increases. M.W.R.

Review: This paper will be somewhat difficult to follow for those who have not been working in this field and are thus not reasonably familiar with the notation (most of the notation is actually specified well except for some angles which are not clearly defined because of the two-dimensional representation of a three-dimensions situation). The strengths are assumed to have a logNormal distribution and the stresses to have a Weibull distribution with a shape factor of 4.5. It should be emphasized that the failure probability is for one load and one set of strengths both selected at random from each of the populations. This is not analogous, for example, to an aircraft where if you wait long enough you will get at least one of each of the loads in the distribution. The latter case would completely fail structures such as the ones in the text since there is always some stress which is higher than a given strength. The structures are statically indeterminate; so elastic theory is used to calculate the stresses in each member (presumably all of them are assumed to have the same Young's modulus). Not all the algebra was checked in this paper but it appears to be competent. The results can be useful in analyzing a structure for which this model is applicable, but they will be very sensitive to the specific assumptions. This is a rather specialized paper and not of general interest to designers and reliability engineers. (The first author in a private communication has pointed out that the method described in the paper is not restricted to the extremal and logNormal distributions which were used in the numerical examples.)

R68-13670 ASQC 844; 713
STRUCTURAL RELIABILITY OF A SIMPLE RIGID FRAME.
Masanobu Shinozuka and Masami Hanai (Columbia University, Department of Civil Engineering and Engineering Mechanics).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 63–67. 3 refs.
(SAE Paper-670616)

Structural reliability of a rigid portal frame subjected to simple loading conditions is determined under a number of assumptions on the properties of the load and on the resistance of the frame. A statically indeterminate frame with three degrees of redundancy is considered, and the resisting plastic bending moments of the beam and the columns are positive random variables. Modes of plastic collapse and domains of integration are illustrated, and it is shown that a minimum weight design under specified reliabilities is possible. Such a design could be compared with the standard deterministic design to provide a more rational measure of safety than that resulting from conventional safety factors. M.W.R.

Review: This paper treats a special case of structural reliability and the example is even more specialized. The paper nevertheless is instructive about the problem of mechanical

failures. The paper will be difficult to follow for those who are not familiar with the mechanics involved and with basic probability notation and theory. The use of probabilities of failure of 0.1% or less requires a knowledge of the tails of the distributions which is rarely available in practice. While this difficulty is acknowledged by the authors, it is worth emphasizing because even for comparative purposes, the calculations may be inadequate. For example when changing from one kind of steel to another or one kind of cross-section of beam to another, the behavior in the tail region may be affected seriously. In the event that one does not wish to use the probability of failure as a criterion, similar calculations can be made using a safety margin: mean {strength-stress}/standard deviation {strength-stress}. In the example in the text, the safety margin would be a function of time.

R68-13672 ASQC 845

AIR FORCE SYSTEM EFFECTIVENESS AND RELIABILITY DATA SYSTEMS.

Milton Haus, John L. Fuchs (USAF, Systems Command, Research and Technology Div., Rome Air Development Center, Engineering Div., Reliability Branch, Griffiss AFB, N. Y.), Emmanuel Denning, and R. H. Schierman (USAF, Systems Command, Ballistic Systems Div., Norton AFB, Calif.)

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 116–139. 8 refs.
(SAE Paper-670623; A67-34658)

Discussion of two Air Force programs for the collection, reduction, storage, analysis, and dissemination of experience data to be applied in the design, development, and acquisition of Air Force systems. The System Experience Correlation and Analysis Program, concerned with the development of a system-effectiveness data-analysis system for use by Air Force System Command Division engineers and program managers, is described, as well as a Reliability Analysis Central, which will be a centralized Air Force clearinghouse for part and device reliability information and experience and will serve as a source of current cumulative reliability knowledge for the engineering and logistic activities of the Air Force and its contractors. IAA

Review: This report on two Air Force data systems will interest those who are seriously concerned with reliability and maintainability analysis. These systems have the potential to supply much of what has been sorely needed for the improved effectiveness of reliability and maintainability analysis. The first one, System Experience Correlation and Analysis Program (SECAP), has received little publicity, and this introduction to it serves a useful purpose. Unfortunately the first part of the paper is marred by the repetition of some of the contents, apparently through typographical errors. The second part of the paper is a timely report on the Reliability Analysis Central, which has already received good publicity. The development of the Central is continuing. This part is well illustrated, enabling the reader to get a bird's eye view of the type of parts reliability data which will ultimately be provided. Several reports on the Central are cited; these will be of use to those who desire more detail. The paper itself is, however, quite comprehensive. The material could have been divided into two separate papers—one for each of the data systems.

R68-13673 ASQC 845

PRINCE/APIC—A CENTRALIZED PARTS AND MATERIALS INFORMATION CENTER FOR THE RELIABILITY ENGINEER.

E. Ray Ritch, Jr. (NASA, Marshall Space Flight Center, Quality and Reliability Assurance Laboratory, Huntsville, Ala.)

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 140–146. 1 ref.
(SAE Paper-67024; A67-34659)

Description of PRINCE/APIC—a parts and materials information center which utilizes a blend of mechanical and electronic methods of data storage and retrieval. The operations of PRINCE/APIC's Data Input Section, which performs all of its data-acquisition and storage functions, and the Inquiry Service, which retrieves and disseminates these data, are described in detail. PRINCE/APIC's storage files and the types of information it has available for the users are discussed. Some PRINCE/APIC usage factors are also presented. IAA

Review: An overview is given in this paper of the current status of the PRINCE/APIC (formerly PRINCE) reliability information program. This program at the NASA Marshall Space Flight Center is the closest activity to a NASA-wide reliability information center. Data programs of this kind are of immense value to the government–industry complex. Duplication of testing and other evaluation efforts is minimized. It is interesting that neither this paper nor the others in this Proceedings concerned with information exchange make any mention of legal problems. Some years ago when these data programs were first contemplated, there was some concern by the government–industry legal personnel that there would be serious antitrust problems [1]. Apparently the desire for improved product reliability in a cost-effective manner has won over the more selfish and narrow viewpoint which was expected by some. It is well to remember, however, that these data programs do not provide all of the information that one may want, and that the data are raw and possibly from poorly-run tests.

Reference: [1] Edward F. Howrey, "Product Standardization and Technical Data Exchange Under the Antitrust Laws," Proceedings Sixth National Symposium on Reliability and Quality Control, 1960, pp. 308–312

R68-13674 ASQC 846; 841; 874

THE UTILIZATION OF INTEGRATED DATA COLLECTION AND ANALYSIS IN RELIABILITY/MAINTAINABILITY PROGRAMS.

S. Pollock (U.S. Naval Fleet Missile Systems Analysis and Evaluation Group, Corona, Calif.)

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 147–174.
(SAE Paper-670625; A67-34660)

The paper presents a Navy (Special Projects Office) method of integrating all reliability data obtained from testing, inspection, and trouble and failure reporting by means of an Integrated Data Plan. Because one of the data inputs to this system is from trouble and failure reports, the paper presents the Special Projects Office Trouble and Failure Report (TFR) program for the Fleet Ballistic Missile Weapon System to illustrate how data are utilized to enhance the quality/reliability/maintainability of a weapon system. The paper also discusses data exchanged and utilized through two nationally known programs—the Interagency Data Exchange Program (IDEP) and the Failure Rate Data (FARADA) program. Author (IAA)

Review: Of the four topics treated in this paper two are Navy-oriented (integrated data plan and the trouble and failure reporting (TFR) program) while the other two pertain more broadly

to the government-industry complex (IDEP and FARADA). Each of these topics is clearly described and well illustrated. The description of the integrated data plan, by its nature, contains broad requirements and general words. The TFR program is a more specific topic and has some years of historical experience behind it. The IDEP and FARADA programs have undergone recent changes and expansion not generally known to all reliability workers, and this paper served to enlighten those who are non-participants in these programs. For readers especially interested in reliability data at the material/part/component/module level, this paper could be valuable.

R68-13680 ASQC 844; 711; 714; 782

INCIPIENT FAILURE DETECTION—THE DETECTION OF CERTAIN CONTAMINATING PROCESSES.

Harvey L. Balderston (Boeing Co., Seattle, Wash.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 245–260. 4 refs.

(SAE Paper-670633; A67-34665)

Results of a study of contaminating processes in integrated circuits. At least four of the contaminating processes (three electrolytic and one galvanic) are identified, as well as the principal pre-existing and process-produced contaminants, and the conditions which appear to accelerate the processes. Although these processes occur extremely slowly under ambient conditions, they are found to occur much more rapidly where condensation of water vapor occurs. The use of certain nonhydrogenous conformal coatings is found to eliminate or control at least three of these destructive processes. IAA

Review: Recognition of these contamination-triggered failure possibilities is important for high reliability. Their existence and the use of conformal coatings to minimize their action constitute important information to reliability engineers. However, there are four main difficulties with the report, and these are discussed below. The concluding statement of the author's introductory abstract (the last sentence on p. 245), "these destructive contaminating processes may very well be a greater source of integrated circuit failure than any other currently known source" must be qualified. The destructive contaminating processes investigated are those characteristic of closely spaced soldered joints on *printed circuit boards.* These effects are external to the integrated circuit chip and package and are applicable only to a particular way of mounting integrated circuits. Two package-related failure mechanisms are discussed—(1) at operating voltages lead oxide glass in the package of an integrated circuit can be reduced to form a lead deposit which shorts adjacent Kovar leads and (2) the galvanic corrosion of the Kovar leads themselves. The Kovar reduction is accelerated by high humidity. Both visual observations and noise measurements can be used to detect the presence of the reduced lead. The solution is to eliminate lead oxide sealing glass from the integrated circuit flat pack. The correlation between noise voltage and visual contamination, described by the author as high, is still low enough so as not to substantially alter previous reservations about noise measurements as indicators of incipient failure (see R67-13423). Electrochemical processes are noisy but their intermittent start–stop characteristics complicate the interpretation of their contribution to noise measurements. The paper is not efficiently organized and appears in places to have been assembled by piecing together parts of independent documents. For example, the figures appear in an order different from that in which they are cited in the text; certain figure numbers clearly are wrong, evidently not having been changed from a previous document. The flow of ideas is not smooth, switching back and forth abruptly between package glass results and printed circuit board results, between normal humidity results and 100% humidity results.

R68-13682 ASQC 844

FACTORS DEGRADING RELIABILITY IN THE USE PHASE.

S. J. Kasper (Westinghouse Electric Corp., Atomic, Defense and Space Group, Defense and Space Center, Baltimore, Md.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 284–291.

(SAE Paper-670636; A67-34667)

Review and extension of results for an EIA (Electronic Industries Association) Reliability (G-41) Committee Task to determine factors degrading reliability in the use phase and provide a basis for design improvements. A matrix of potential degradation factors and measures of significance are used in development of analysis methods to determine optimum correction modes in terms of cost and time. Recommendations include a realistic downtime model and considerations for design analysis to aid in improving use reliability. Author (IAA)

Review: This paper uses reliability in a general sense rather than in the narrow sense (probability of failure) in which it is sometimes defined. It is a theoretical paper, since it provides a framework for looking at the actual situation; it discusses the philosophy of preparing a check list. The check list itself is an appendix to the paper. Most of the factors or items which are listed are not things which users do to damage the equipment but are considerations during the project definition, design, and production phases. It would seem more appropriate to title the paper, "Factors which influence the reliability (viz., cost effectiveness) of the equipment." It is obviously directed toward electronics rather than mechanical devices. This is natural from an EIA committee. For example, circuits which rapidly age out of tolerance limits are considered, but there is no mention of designing against fatigue. Many of the items are under the direct control of the designer, for example, shock and vibration resistance, and adequacies of protection against other environments. All in all the check list is a good one for the designers and planners to have available. Some of the items need to be interpreted imaginatively. For example, nothing explicitly discusses the ease of maintenance or the possibility of doing damage to the equipment while maintaining it, but they could be said to be included under "time-phased action area (7) Maintain." There are people and groups for whom this document will fill a need, but it is not universally applicable for designers.

R68-13683 ASQC 844; 543; 770; 850

RELATIONSHIP BETWEEN DEMONSTRATED AND OPERATIONAL RELIABILITY.

H. Dager (ARINC Research Corp., Washington, D.C.) and R. Saum (U.S. Navy, Washington, D.C.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 292–304.

(SAE Paper-670637; A67-34668)

Results of a study of the relationship between acceptance-test and operational reliability, using multiple-regression analysis. In

addition to determining inherent hardware reliability, other factors, such as equipment descriptors, data-collection methods, and a combined environmental mission and application descriptor, are taken into account. The data obtained as a result of the survey are summarized in tabular form, but fall into many classifications, due to the variety of equipment types, the wide range of missions of the equipment, and the variation in estimating and testing. IAA

Review: The relationship between operational reliability and prior estimates obtained either by prediction with generic failure rates or by estimation from equipment test results has long been of interest (e.g., see R66-12448). This paper discusses two investigations using empirical data from equipment programs. The anonymous organizations supplying data in the EIA survey are to be commended for their participation. It is regretful, however, that data were inadequate to permit a thorough analysis of the desired relationship. The available data are of interest, however, and illustrate some of the disparity between estimated and actual reliability. The second study using available in-house and Navy data on airborne equipments involved the development of some empirical equations between demonstrated and operational MTBF. Whereas the formulae apply only to the equipment studied, they do serve to illustrate that differences between the two can be significant and that other factors such as equipment complexity and mission characteristics can have a large bearing on the relationship. The argument of Equation (1) should be corrected to read θ_A.

R68-13686 ASQC 844; 770; 782

ENVIRONMENTAL TESTING OF ELECTRONIC COMPONENTS—PARTS 1, 2, AND 3.

C. J. Hansford (Ministry of Aviation, Electrical Inspection Directorate, Bromley, England).

Electronic Components, vol. 7, Mar., Apr., May 1966, p. 229–236; 341–345; 462–466.

Mechanical, humidity, temperature, corrosion, low air density, and combined tests are considered in terms of environmental testing requirements of the electronics industry in Great Britain. Specifications, both British and American, are discussed for mechanical tests of acceleration, bumping, shock, vibration, and robustness of terminations; and the installation and use of accelerators and vibrators is covered. Salt solution and moisture injection chambers for damp-heat tests are discussed; and attention is given to the use of humidity chambers and the measurement of humidity, as well as to mold growth associated with humid conditions. Testing at both low and high dry temperatures is detailed. Salt mist, industrial atmosphere, and solvent resistance corrosion tests are discussed; and types of measuring devices are listed for performing low air density tests. Mention is made of the sequence for performing these tests. M.W.R.

Review: This three-part paper deals largely with British practice and what their requirements might become. It is a good though necessarily brief discussion of what one is testing for and how one goes about testing for it. The first part deals with mechanical tests and by far the largest portion of it is devoted to vibration. The second part considers high humidities and extremes of temperature. These are accelerated tests and suffer from the difficulties usually associated with them. This part deals more with the equipment required to meet certain conditions and the mechanics of the test than it does with extrapolating the results of these tests to field performance. The third part deals with corrosion and air pressure. The details of how a test is run and why it is different from running it another way are well handled. The methods of applying low pressures to the specimens are dealt with in some detail. The series is concluded by short discussions of the sequencing of tests and the combining of environments. These discussions are in the nature of describing usual practice rather than trying to delve into any of the tricky practical problems involved in test interpretation. All in all this series is not too long and is well done for what it purports to be, namely a description of testing methods as opposed to testing interpretation.

R68-13694 ASQC 844; 711; 714; 782

WHEN PARTS FAIL AT ELEVATED TEMPERATURES.

Alvin E. Nehrenberg (Wallace–Murray Corp., Simonds Steel Div., Lockport, N. Y.).

Metal Progress, Nov. 1967, p. 76–82.

Failures that result from excessive creep, stress rupture, or thermal fatigue are considered; as are malfunctions due to catastrophic oxidation, hot corrosion resulting from carburization, nitriding, sulfidation, exposure to molten metals, and preferential oxidation of chromium carbide or chromium sulfide. The need for tests is noted in this discussion of component failures at high temperatures. Failures due to creep are discussed in detail, oxidation and scaling as well as scales that offer protection, and corrodents in fuels are described. Attention is given to green rot and its cure, and to the effects of molten metals on heat-resisting alloys. M.W.R.

Review: This paper is a collection of examples and a few principles to illustrate how metallic parts will fail at high temperatures; it serves more to create awareness of problems than it does to list orderly solutions for as many cases as possible. The paper can cause mechanical engineers to realize that they will need the help of metallurgists in this area and that rules of thumb will probably buy them little but grief. The knowledge of failure modes is an essential part of high reliability in design and production. This paper gives good examples of many of them for refractory metals at high temperatures.

R68-13701 ASQC 844

Battelle Memorial Inst., Columbus, Ohio.

MICROELECTRONIC STUDIES Final Report

B. C. Peralta, J. W. Klapheke, A. B. Timberlake, C. G. Kopp, and J. L. Easterday 25 Mar. 1966 194 p refs

(Contract N62269-3111)

(AD-644198; N68-80217)

Screening practices for microelectronics equipment are reviewed, and the modeling of transient behavior of microcircuits is considered. Screening techniques of potential use for silicon integrated circuits were studied; and experiments with NOR gates indicated that parameters measuring low frequency noise and transfer characteristics appear to be useful for empirical screening. Failure-sensitive parameters and related failure modes were investigated, and noise was considered as a failure-sensitive parameter for integrated circuits. Experiments in inducing and detecting surface defects were undertaken; and the relationship of surface phenomena to planar silicon device reliability was determined. Consideration was also given to the X-ray inspection of integrated circuits, gamma radiation as a preconditioning stress to aid screening procedures, spectra of an intermittent device, and basics of device failure analysis. M.W.R.

Review: The value of this report lies in its comprehensive review and summary of the literature on screening techniques for integrated circuits and on the failure modes common to integrated circuits. The experimental work reported is preliminary and its significance is not yet clear. The coverage of existing screening techniques is thorough, detailed, and in places original. The search for precursors of failure—the development of satisfactory screening techniques—is unfinished. Thermal resistance and, to a lesser extent, I/f noise (and other noise) appear to be the most promising screening measurements in the authors' opinion. Task 2, the modeling of transient behavior, is confined to an appendix. This task appears to be independent of (although related to) the investigation of screening methods that makes up the bulk of the report. Indeed the

modeling work appearing here seems to be a continuation of previous modeling referenced only by contract number. As such it is of less interest when read independently than if the previous work were readily available. (The first author in a private communication has indicated that the final report containing the earlier transient modeling development for integrated circuits was entitled "Microelectronic Studies" dated July 15, 1965.)

R68-13702 ASQC 844; 711; 712; 713
HOW COMPONENTS FAIL.
Donald J. Wulpi (International Harvester Co., Engineering Materials Research, Hinsdale, Ill.).
Metals Park, Ohio, American Society for Metals, 1966, p. 1–56. 21 refs.

A series of articles is presented based on information in an industrial failure analysis manual on mechanical parts such as shafts, gears, and bearings. Modes of fracture, types of loading, and effects of variables are discussed; and characteristics of fatigue fractures are noted. Surface damage is considered in terms of effects of wear, fatigue, and corrosion; and some surface damage in gears is described. Bending and tensile failures as well as torsional failures in shafts are reviewed, and fracture in gear teeth is discussed. M.W.R.

Review: This booklet was adapted from a series of articles and is an excellent source of information for design and test engineers who are concerned with mechanical parts. The concern is largely with shafts, gears, bearings, and like components. The material is written on a practical level and requires a minimum background in metallurgy and mechanical engineering. The emphasis is largely on the materials and the stresses. The implicit philosophy about failures seems to be that it is always the material that fails, which of course is true and should be remembered by the engineers. The object is to design the part so that premature failure will not occur and to have some criterion for likelihood of failure as a function of position within the component (e.g. stress versus strength). Very often one wishes to make this likelihood uniform throughout the part. At other times, e.g., for safety purposes, one may wish to have certain portions unlikely to fail. Even those engineers who consider themselves in the field of electronics rather than mechanics would do well to review a booklet such as this because many electronic failures are in fact mechanical failures of the materials. The book is more suitable for reading through to get a general background than it is for a reference handbook.

R68-13705 ASQC 844; 775
Lockheed Missiles and Space Co., Sunnyvale, Calif.
DETECTION OF FLAWS IN ADHESIVE BONDED METALLIC HONEYCOMB BY INFRARED NONDESTRUCTIVE TESTING
F. E. Alzofon and W. A. Rohr Presented at the 1966 Spring Conv. of the Soc. for Nondestructive Testing, Los Angeles, 7–10 Mar. 1966. 24 p refs
(N68-81551)

Correlations are found between infrared radiant emittance variations and the location of known flaws in an adhesive bonded metallic honeycomb panel used in the aircraft industry. The test specimen was a 24" × 12" × 1/2" honeycomb structure fabricated with three different thicknesses of aluminum core ribbon, using FM 1000 adhesive, and sandwiched between two aluminum plates. Specimen surfaces were cleaned and painted with zinc chromate primer to increase surface emissivity and decrease variations in emissivity; and a constant heat source was applied to one surface, while the other was cooled by forced convection to insure conditions for optimum signal detection. All flaw indications were projected onto the cooled surface, and there was no difference in data obtained from scanning either of the sides. Results indicate good correlation between these thermal recordings and ultrasonic nondestructive testing. M.W.R.

Review: This is a good brief paper which reports the results of a specific experiment on nondestructive testing. It is noteworthy in that it explains well the differences between nondestructive testing and reliability analysis and that it clearly states the assumptions and limitations of the experiment and its interpretation. Furthermore, it gives a very good introduction to the use of infrared testing. The exact data are by now of less concern than are the qualitative aspects of the paper. It is suitable for design and reliability engineers. In a private communication the first author has stated that two important results of the study were (1) the demonstration that *metallic* substances could be examined by infrared scanning with positive results in the detection of flaws and (2) the demonstration that the complex structure of the honeycomb (also metallic) did not interfere significantly with the detection of the inserted flaws, and that these results are still pertinent.

85 DEMONSTRATION/MEASUREMENT

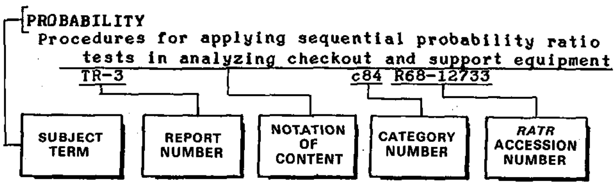
R68-13666 ASQC 851; 770
INVESTIGATION TO DEVELOP OPTIMUM SHORT-TERM SCREEN TESTS FOR INTEGRATED CIRCUITS.
D. A. Cross and W. R. Rumpza (Boeing Co., Seattle, Wash.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 3–11. 4 refs.
(SAE Paper-670610; A67-34649)

Description of a technique for utilizing life distributions of integrated circuits obtained under high-stress testing to establish reliability screening criteria. The basic factors controlling observable lot behavior and the manner in which they dictate a test approach are discussed. The typical life-expectancy distributions obtainable from currently used devices are analyzed, the probable escape rates of defective devices are estimated, and the manner in which the expected life of accepted devices may be altered by stress screening is outlined. The existence of device threshold-stress-level capabilities from which the screenability of lots can be determined is established. IAA

Review: While the subject of this paper is worthwhile, its execution is poor. The two main defects are an extremely poor editorial review and a style of writing which presumes that the reader will be as familiar with the details of the process as the authors are. Examples of editorial defects are (1) the labels of the graphs in Figs. 3–5 (the vertical labels are either wrong or without much meaning), and (2) a paragraph on page 7 (describing device degradation at low levels near the threshold stress) does not make sense. In the description of the actual test program, integrated circuits are said to be reverse biased and the power dissipation is given; the term reverse-bias is not applicable to an integrated circuit but to a junction and when junctions are reverse biased, especially the size on an integrated circuit, dissipation of 300 mW would be appreciable (since M stands for mega- and m for milli- it would have behooved the authors to use an mW rather than MW, although from the context one would doubt that MW was really meant). Much of the paper is a description of what is hoped will come out of the program; only a small part gives tentative results. There is apparently confusion about the meaning of the concept of stress-capability and there is similar looseness in several other places in the text, so that the authors' meaning is not clear. All in all, the paper is not recommended as a source of information.

SUBJECT INDEX

Typical Subject Index Listing



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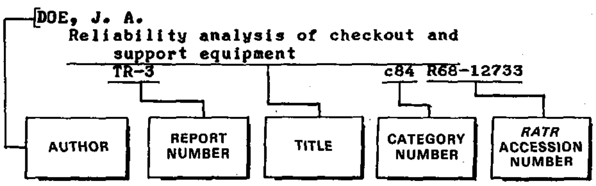

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 3

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

***RATR* ACCESSION NUMBER**	R68-12733 ASQC 844; 413	**ASQC CODES**
	General Equipment Company, Banville, Calif.	**CORPORATE SOURCE**
TITLE	**RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT**	
AUTHOR	John A. Doe 23 Sep. 1966 27 p refs	**PUBLICATION DATE**
CONTRACT OR GRANT	(Contract NAS15-13411)	
REPORT NUMBER	(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65	***TAB* AND *STAR* ACCESSION NUMBERS**; **SALES AGENCY AND PRICE**

***RATR* ACCESSION NUMBER**	R68-12739 ASQC 814	**ASQC CODE**
TITLE	**SEMICONDUCTOR RELIABILITY**	
	Joseph A. Smith (Eastern University, Arlington, Penn.)	**AUTHOR AND AFFILIATION**
JOURNAL REFERENCE	*Electric Journal,* vol. 8, Apr. 1966, p 478–492.	
	(A68-12569)	***IAA* ACCESSION NUMBER**

***RATR* ACCESSION NUMBER**	R68-12765 ASQC 773; 221; 823	**ASQC CODES**
TITLE	**TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES**	
	Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)	**AUTHORS AND AFFILIATIONS**
CONFERENCE OR SYMPOSIUM REFERENCE	*Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p*	
	Available from Assoc. of Reliability Eng., New York: $1.00	**AVAILABILITY AND PRICE**
***IAA* ACCESSION NUMBER**	(A68-12407)	

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Reliability Abstracts and Technical Reviews

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80 RELIABILITY

R68-13706 ASQC 800

Rome Air Development Center, Griffiss AFB, N. Y.

RELIABILITY PREDICTION—TODAY AND TOMORROW

Anthony J. Feduccia Jan. 1967 33 p refs Presented at the 1966 Spring Seminar at IEEE Reliability Group, Boston, 14 Feb. 1966

(RADC-SP-66-8; AD-645743; N67-22612) CFSTI: HC $3.00/MF $0.65

Reliability prediction techniques are usually divided into two categories: (1) feasibility (or ballpark) prediction procedures and, (2) design (or stress analysis) prediction procedures. This report briefly describes existing techniques in each category and outlines their capabilities, shortcomings and limitations. Suggestions for developing new prediction techniques and for expanding present methods are also presented. Author (TAB)

Review: This is a tutorial type of paper but since it is philosophic and reflective, it can be of value to engineers who are not beginners. The various electronic reliability prediction methods are described and some of their more important characteristics given. For the experienced reliability engineer the paper will appear overly long, but the beginner may appreciate the detail. It is a paper easier listened to at a conference (where it *was* given) than it is to sit down and read. Even though it might be worth their while, few engineers will take the time to read it.

R68-13709 ASQC 815; 840; 850

BACKGROUND AND CONTENT OF MIL-STD-781A.

C. G. Wigginton (U. S. Naval Ammunition Depot, Crane, Ind.).

In: Proceedings of the 1966 Spring Seminar on Reliability Techniques... Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 7–17. 7 refs.

Primary requirements are presented for MIL-STD-781A, which outlines a series of test levels and test plans for the qualification and sampling phases of reliability production acceptance tests for nonexpendable electronic equipment. Ten test levels or stress levels are given as statistical parameters for determining equipment reliability, and ground rules for performing the tests are included. Probability Ratio Sequential Tests (PRST), short-run high-risk PRST's, fixed length tests, and longevity tests are included in the 28 test plans of the standard. There is no consideration of sampling risks in the statistical basis for the test plans. Various conditions precedent to reliability tests that are discussed include failure rate prediction, design and performance, thermal survey, burn-in, and cycling. Test chambers, vibration, and equipment cooling are considered; and mention is made of censorship, failure analysis, corrective action, and records. M.W.R.

Review: This paper presents the primary requirements of MIL-STD-781A and discusses the background of many of them. It is apparently preliminary to, and contains some of the same material as, the paper covered by R67-12947, which was presented three months later by Henry R. Thoman and the present author. The review comments regarding MIL-STD-781A in R67-12947 are pertinent to this paper also.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13710 ASQC 813

U. S. ARMY ELECTRONICS COMMAND'S RELIABILITY PROGRAMS.

John P. Sosdian (U. S. Army Electronics Command, Research and Development Directorate, Fort Monmouth, N. J.).

In: Proceedings of the 1966 Spring Seminar on Reliability Techniques... Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 19–29.

Aims, accomplishments, and current reliability programs of the U. S. Army Electronics Command (ECOM) directorates and laboratories are discussed in terms of in-house and contractors efforts. Organizational elements responsible for the overall ECOM reliability program and their functions are described, and current regulations are included. The 10 basic elements of the reliability plan, based on operational and planning information, are included, along with the applicable reliability documents. Mention is made of reliability training, the reliability intern program, and operation woodpile which provides reliability training and experience at Fort Huachuca. Both internal and external efforts of the Electronic Components Laboratory of ECOM are discussed, including equipment and systems development programs, engineering development, production of lead time, reliability incentives, and cost of reliability testing. Efforts at the Procurement and Production Directorate of ECOM are also noted, including the light observation avionics package, reliability data bank, electronic parts program, and materiel readiness program. M.W.R.

Review: This is a good paper and will be helpful to those who wish to learn more about the U. S. Army Electronics Command's reliability programs. It is presumed that the descriptive material is adequate. The balance of the paper is of the usual management type which describes a nominal program. The effectiveness of any such program is influenced to a high degree by the actual people in a position to effect it. Competent, interested, and agressive people will carry out the programs perhaps even better than their originators had hoped for. At the other end of the spectrum virtually nothing may get done and, if it does, it may cause more dissention than help. The paper does not elaborate on DoD policies of any sort or attempt to interpret them, so is not useful from that point of view.

R68-13718 ASQC 816; 813

SUBCONTRACTOR RELIABILITY CONTROL.

Donald C. Berman (TRW Systems, Inc., Systems Engineering and Integration Div., AGE Reliability Section, Redondo Beach, Calif.).

In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodical Co., May 14, 1966, p. 23–30.

Subcontractor reliability control is considered under the headings of (1) identification and definition of requirements, (2) survey and approval of sources, (3) negotiation of tasks and costs, (4) implementation of the program, and (5) documentation of performance. The need for subcontractor reliability control is stressed in terms of the interrelationships of components, systems, and total products. And, although the implementation of formal reliability programs at the component level may not be required by government agencies in the near future, a trend has been established and systems contractors will find such implementation in their own best interests. M.W.R.

Review: This paper is typical of many that describe a reliability program. They can be of interest to program managers who wish to create such a program or to compare it with theirs. The program as described seems reasonable and probably is of benefit both to the subcontractors and to the company. Surveys, while useful, have gross limitations. In virtually all descriptions of such programs the day-to-day kinds of problems are not discussed in detail. These are the kinds that can foul up almost any well-intentioned program: e.g., there are various kinds of pressures from above for production deadlines and cost reductions; these programs are all implemented by people, they do not implement themselves. As with virtually all such programs one of the initial requirements is to start off with good people in the group. As long as the number remains very small this can be easy, but as soon as the number becomes large, on the average there will be average people in the group (a fact of life that it is hard to get away from).

R68-13720 ASQC 814; 813

COST ANALYSIS OF RELIABILITY PROGRAMS.

Gerald R. Greenfield (North American Aviation, Inc., Space and Information Systems Div.).

In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, 1966, p. 93–107. 4 refs.

Two cost analysis methods for determining program reliability are discussed; one method uses component or system reliabilities, while the other makes use of the maintenance and replacement records. Details are presented for cost analyses by both methods; and tables summarize the data obtained by both methods for an amplifier, an actuator, and an engine controller. These data indicate the costs of improvement programs in terms of cost savings and higher reliability. An incremental savings analysis is summarized to indicate the relationship between improvement cost, the expected gross savings, and expected net savings with respect to reliability and mean time between failure. M.W.R.

Review: This is one of the standard approaches to the problem and is reasonably well explained. Statistical independence is implicitly presumed in the multiplication of reliabilities; very likely this could have been done away with by the use of conditional probabilities. The time value of money is taken into consideration. It is not made clear in the paper that this is just one of the approaches; viz., there are figures-of-merit other than average cost which are important. The important thing for beginners to do when reading a paper such as this is to distinguish between learning this particular method and learing that this is *the* method to use. It would have been helpful at the end to summarize the exact assumptions being made, to make it easy to see whether or not this model is the one desired in a specific instance. For example, some of the things not considered are that for a given change there may be both a reliability and a maintenance effect; there may be a learning effect, if something new is introduced; and there may be a logistics effect.

R68-13722 ASQC 815

RELIABILITY REQUIREMENTS FOR EXTENDED SPACE FLIGHTS.

W. A. S. Douglas (Aerospace Corp.).

In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, p. 121–126.

Reliability in design and manufacturing phases is considered for equipment required for extended space flights, and some of the methods that can be used to enhance reliability are noted. Attention is given to redundancy of critical components, in-flight repair, and standardization. The need for high reliability components is mentioned, as are procurement and test specifications that will increase reliability. Other aspects of high reliability systems that are discussed include traceability, work instructions, environmental control, testing, and failure analysis. M.W.R.

Review: This is a philosophic paper which discusses the problems of extended space flights. As such it is of value and many of the suggestions are good ones. In any practical situation where hardware is concerned, it is wise to state the requirements and the non-requirements in as much exactness and detail as possible so that the engineers who are searching for solutions have as wide latitude as feasible. For example, the author says that certain small parts should be X-rayed; what he probably means is that they should be subjected to some kind of nondestructive test on the inside to see what is there—without being specifically limited to X-rays.

R68-13737 ASQC 817; 833
THE RELIABILITY OF THE LUNAR ORBITER POWER SUBSYSTEM.
Louis Gomberg (Radio Corp. of America, Defense Electronic Products, Astro-Electronics Div., Princeton, N. J.).
Space Congress on the Challenge of the 1970's, 4th, Session 6—Vallue Analysis Quality Control and Reliability, Cocoa Beach, Fla., 3-6, 1967, 5 p.
(A67-36594)

Discussion of the basic Lunar Orbiter power subsystem and the reliability trade-offs, including methodology. The system selected is described as well as the techniques to insure that the design reliability is maintained in fabrication. Actual spacecraft performance parameters are compared to predicted values. An illustrative calculation of the reliability of the Lunar Orbiter battery is given; the reliability is found to be 0.9998. IAA

Review: This paper is addressed to a rather specific topic—the selection and development of a reliable power subsystem for a particular spacecraft. The reliability which has subsequently been demonstrated for this particular subsystem attests to the effectiveness of the approach which was used. Thus, the paper has merit as a description of a technique which has potential applicability on other programs. Topics covered include: reliability tradeoffs, component selection with reliability in mind, and techniques to insure that the design reliability is maintained during fabrication. These are covered in sufficient detail to give a knowledgeable reader a good picture of what was done.

R68-13741 ASQC 810; 300
THE FIRST DOD CONFERENCE ON QUALITY AND RELIABILITY MANAGEMENT.
Edwin S. Shecter (Radio Corp. of America, Astro-Electronics Div., Princeton, N. J.).
Industrial Quality Control, vol. 24, Nov. 1967, p 250–252. 2 refs.

A general review is presented of the first Department of Defense conference dealing with quality control and reliability management. More than 130 representatives from various government agencies attended the conference, which was divided into nine panels concerned with concepts, development aspects, production, storage, maintenance assessment of reliability and maintainability, personnel and training, metrology and calibration, and the quality of technical data. The conference developed 166 recommendations, for action, and some of the more important ones are discussed. M.W.R.

Review: This is a brief presentation of some of the more important recommendations developed at the First DoD Conference on Quality and Reliability Management. The Proceedings of this conference were covered by R68-13551.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13714 ASQC 824; 864
RELIABILITY SCOREBOARD, A NEW TOOL FOR RELIABILITY ASSESSMENT.
Gerald J. Plotkin (Raytheon Co., Wayland, Mass.).
In: Proceedings of the 1966 Spring Seminar on Reliability Techniques...Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 63–69. 11 refs.

A reliability assessment procedure that results in a Reliability Scoreboard is based on field removal data that are systematically processed to give information on maintainability performance and, thereby, evaluate existing reliability. The removal data used in the reliability assessment procedure performed for the Navy consist of customer's failure reports, commanding officer's narratives, module repair data from customers and vendors, and field engineer's reports. Engineering review of these removal data consists of both a preliminary screening procedure and data synthesis; and mean time between failure (MTBF) data are computed from processed removal and time data for the system, subsystem, module, and part levels. It is noted that the MTBF charts for individual ships indicate variation from vessel to vessel. M.W.R.

Review: This paper is virtually identical to the one covered by R67-13416 which was given over one year later, although no reference was made to the earlier discussion. The review given for the later paper is applicable to this one also.

R68-13717 ASQC 824
A PROCEDURE FOR ESTIMATING PERFORMANCE AND RELIABILITY TREND EFFECTS.
Joseph J. Cynamon (Raytheon Co., Space and Information Systems Div.). and W. Gordon Cawood (Northrop Nortronics, Precision Products Dept.).
In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, 1966, p. 13–21.

A measurement and computation technique is developed to assess a trend effect in the statistical performance qualities of a system or a device, for which the aggregate of performance measurements will fit some distribution at any one point in time. The equations presented provide a means of determining system or device behavior at succeeding points in time and, thereby, provide a running plot of statistics that effectively monitor performance and weigh the acceptance of new data on statistical adherence to previous history. The procedure employed is detailed, and an example with 100 points of past history is considered. Computations are included for determination of mean difference ratio, standard deviation difference ratio, and probability density function difference ratio. M.W.R.

Review: The disadvantages of writing a paper in which the mathematics is easily checked and understandable are that people may check it and try to understand it. The quantities considered significant by the authors (not using their notation since it is not very standard) are: 1a. $\delta\mu/\mu = \sigma/\mu \cdot Z_n/n$; b. $\delta\mu/\sigma = Z_n/n$; 2. $\delta\sigma/\sigma = Z_n^2/2n$; 3a. $\delta f(Z)/f(Z) = (Z^2 - 1)\, Z_n^2/Z_n + Z \cdot Z_n/n$; b. $\delta f(Z_n)/f(Z_n) = Z_n^2/Z_n\, (Z_n^2 + 1)$ where Z is the standard Normal deviate and Z_n is the nth datum. The author has calculated 3b. incorrectly; the disadvantage in using the author's method of combining differentials and algebra is that the assumptions involved in the differentials get lost. The equations are true only if $\delta\mu$ and $\delta\sigma$ are small (which means that second-order terms in the expansion are small compared to the first-order terms). There are two big disadvantages in using these formulas (even presuming that the correct formulas are used): 1. As n becomes large, each one of the figures-of-merit approaches zero. For example, if the 200th datum is at 20σ, it would probably be accepted! 2. The quantities are not statistically independent as a function of n so that it is extremely difficult to analyze their behavior, in terms, for example, of confidence limits or limits of any kind. There are texts and papers on cumulative sum charts and analyses. There are also standard statistical methods for keeping track of important quantities even when there is a trend in the parameters of the distribution. They should be consulted in preference to this paper.

R68-13721 ASQC 824; 540

RELIABILITY MEASUREMENT BY REGRESSION ANALYSIS.

D. R. Jackson and D. R. Taylor (Martin Co., Denver Div.).

In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, 1966, p. 109–120.

A reliability growth equation regression analysis technique for analyzing space system test results is presented as a means of estimating operational reliability as a function of test articles. Tradeoffs resulting from variations in moving sample sizes, ultimate reliability asymptotes, and several growth equations are presented; and such tradeoffs for past programs provide the basis for realistic system reliability design criteria, operational goals, and system effectiveness input data. Details are included for both the derivation of regression analysis and the use of least squares method for reliability measurement; and various reliability growth equations are included. The method of regression curve optimization is discussed, and the implementation of reliability measurements by regression analysis is considered. M.W.R.

Review: This paper is virtually identical to the one presented about six months later and covered by R67-13321.

R68-13724 ASQC 821; 414; 838

OPTIMIZATION OF RELIABILITY AND STRUCTURE OF HIERARCHIC CONTROL SYSTEMS 1. RELIABILITY OPTIMIZATION.

A. I. Koekin

(Avtomatika i Telemekhanika, vol. 26, Oct. 1965, p. 1764–1770.) *Automation and Remote Control,* vol. 26, July, 1965, p. 1707–1712. Translation.

Economic criteria are used to optimize the reliability and structure of hierarchical control systems; and tradeoffs between effective control and cost considerations are considered. The relationship of the reliability of the apparatus of such a system to the rank of the degree of control it affords is established for the case of systems for which control is exercised from a central controlling dispatcher station. At the intermediate points in the system, only information gathering and processing take place. It is assumed that system structure is symmetric, and that the so-called controlled plants are homogeneous in composition. It is shown that as the degree of control increases, the reliability also increases. Reliability characteristics of a system are discussed in general terms. Derivation of the regret or utility loss function is detailed, and minimization of the function is considered. M.W.R.

Review: This is a theoretical paper which optimizes the loss function of a system by postulating that the achievement of low failure rates costs money, and by assuming a particular kind of loss function during operation. The loss of any subsystem is considered to have an effect on each of the sub-missions of the system. All of the sub-missions are weighted equally and the loss matrix can be assigned with regard to subsystems and sub-missions in a matrix form. *Zero* indicates no effect of subsystem failure on the sub-mission, and *one* indicates failure of the sub-mission if the subsystem fails. Additivity of losses is assumed. The mathematics itself appears competent, although it was not all checked. An engineer will have to be reasonably familiar with vector/matrix notations and operations in order to follow the paper. The translation itself is fairly good and does not limit understanding. The results are a useful although quite specialized addition to the theoretical structure of reliability analysis and apportionment. Several special cases are analyzed, but the relationship of the answers to other formulations of optimum redundancy is not considered. (See pp. 1945–1951 in the same journal for Part II of this paper.)

R68-13726 ASQC 821; 414; 838

OPTIMIZATION OF RELIABILITY AND STRUCTURE OF HIERARCHIC CONTROL SYSTEMS. 2. OPTIMIZATION OF STRUCTURE.

A. I. Koekin

(Avtomatika i Telemekhanika, vol. 26, Nov. 1965, p. 2019–2025.) *Automation and Remote Control,* vol. 26, July, 1965, p. 1945–1951. 3 refs. Translation.

An equation for the utility loss function (derived in R68-13724) is the basis for the optimization of the structure of a hierarchical control system. Two methods of optimization are considered when the system structure does not enter explicitly into the loss function; these include transformation of the initial system or search for an optimal system in the class of similar systems. Costs are related to the number of levels of control in a system, and a cost vector is included in determining total system loss and in developing the optimal structure for a hierarchical control system. Cost of the communications channels are then determined as a function of the system structure. Equations are also evolved for deviation of the loss function. M.W.R.

Review: This is Part II of the paper on pp. 1707–1712 in the same journal and is a continuation of the theory. In some respects the mathematical language is more complicated than in Part I. Probably only those who are continually involved in theoretical research will find a use for this paper. The results for some special cases are also derived and there is one numerical example to help in understanding. As with Part I, the paper does make a good, although specialized, contribution to the theoretical framework of reliability. It will be of little direct use to design engineers.

R68-13728 ASQC 823

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

SOME INEQUALITIES FOR STARSHAPED AND CONVEX FUNCTIONS

Richard E. Barlow (California Univ., Berkeley), Albert W. Marshall, and Frank Proschan Aug. 1967 40 p refs *Its* Math. Note 519

(D1-82-0643; AD-660072; N68-11071)

Necessary and sufficient conditions are obtained on a function G of bounded variation such that phi(integral sign x(t)dG(t)) = or < integral sign phi(x(t))dG(t) for all increasing x for which x(t sub 0) = 0 for some specified t sub 0, and all convex phi for which phi(0) = 0; the conditions are otherwise independent of phi and x. Similar results are obtained when the inequality is reversed. Necessary and sufficient conditions for both directions of inequality are also obtained when phi is starshaped. The relationship to previous results is sketched. Applications to statistical tolerance limits are indicated. Author (TAB)

Review: Although the research reported in this mathematical note was motivated by certain statistical problems in reliability theory, the applications of the results are only hinted at. It is doubtful that the applied reliability worker could make use of the theorems in "real world" problems. Clearly, the intent of the authors is to write a strictly mathematical paper. A few of the applications have been given in the paper covered by R67-13369 and hopefully more applications will be presented in the near future.

R68-13729 ASQC 823; 413

California Univ., Berkeley. Operations Research Center.

LIKELIHOOD RATIO TESTS FOR RESTRICTED FAMILIES

Richard E. Barlow Apr. 1967 36 p refs

(Contract Nonr-3656(18))

(ORC-67-16; AD-653104; N67-39512) CFSTI: HC $3.00/MF $0.65

Likelihood ratio tests for the problem $H_0: F \epsilon F_1$ versus $H_1: F \epsilon F - F_1$ are defined for certain nonparametric families of distributions F and F_1. In particular the likelihood ratio test is defined and shown to be unbiased when F_1 denotes the exponential distributions (possibly truncated) and G denotes the distributions with increasing failure rate. Comparisons are made with increasing failure rate. Comparisons are made with competing tests. The problem of testing for increasing failure rate average is also examined. Author (TAB)

Review: The value and importance of life distributions which have the property of increasing failure rate average (IFRA) have recently been discovered. The present report will thus be of interest to all students of the modern mathematical theory of reliability and life testing. The report is quite theoretical with many of the proofs relying heavily on the references. If one is willing to forego the proofs, the tests may be carried out quite easily and tables of appropriate critical values (for small samples) are given for two important test statistics.

R68-13730 ASQC 824

California Univ., Berkeley. Operations Research Center.

MINIMAX RESULTS FOR IFRA SCALE ALTERNATIVES

Kjell Doksum Aug. 1967 29 p refs

(Contracts Nonr-222(83); Nonr-3656(18))

(ORC-67-31; AD-660376; N68-12932) CFSTI: HC $3.00 MF $0.65

Let x sub 1, ..., x sub m and y sub 1, ..., y sub n be two independent random samples from populations with continuous ifra distributions f(.) and f(./delta) respectively, and let s sub 1, ..., s sub n denote the ranks of the y's in the combined sample. For testing h sub 0: delta = or < 1 vs. h sub 1 delta > 1 it is shown that the error probabilities of each monotone rank test phi are bounded by the error probabilities for exponential alternatives. Inequalities are used to derive tests that maximize the minimum power in the class of all rank tests. The results are extended to censored samples, sequential sampling, distributions ordered by skewness, the problem of combining independent test statistics, and the goodness to fit problem. Author (TAB)

Review: This report will be readable only to those who have a substantial background in mathematical statistics. The author proposes no new tests, but does prove several optimal properties of previously-proposed tests in certain situations of interest in reliability problems. The mathematics is of a uniformly high caliber, but the proofs do rest quite heavily on the results contained in the references. Thus for a complete understanding of the proofs one must have considerable familiarity with those papers. The author, in a private communication, has pointed out that the results are extensions to finite sample sizes and sequential sampling of the results in his report covered by R67-13418.

R68-13731 ASQC 824; 541

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

LINEAR REGRESSIONAL ANALYSIS OF RESULTS OF FATIGUE TESTS

M. N. Stepnov *In its* Structural Strength of Light Alloys and Steels 13 May 1966 p 17–23 refs

(N67-23523)

Based on the treatment of numerous fatigue test results, an indirect method was obtained for determining the sensitivity threshold for structural aluminum alloys. A statistical method based on linear regression analysis is used to treat fatigue test results which takes into account the sensitivity threshold according to cycles. As an example, treatment is given to the test results of smooth aluminum alloy samples with diameters of 8 mm. The tests were conducted at a pure bend of revolving samples on a fatigue machine at four levels of stress. Test results are tabulated along with values of sensitivity threshold according to cycles and statistical characteristics of scattered life values. The calculation of the parameter dispersion of the regression equation line and the parameter confidence intervals is given. The resulting equation of the line of regression $Y = 18.6833 - 9.4270\ x$, and graphs expression the dependency of dispersion of magnitude log $(N - N_0)$ on the level of stress and the sensitivity threshold from mean value $y = \log (N - N_0)$, are used to construct fatigue curves for different probabilities of destruction for the alloy samples. R.N.A.

Review: The assumptions in this article are not too easy to find but they consist of the following. (1) There is a number of cycles N_0, below which there is no fatigue damage. (2) $N - N_0$, has a log Normal distribution. (3) Log N_0 is directly proportional to the mean of log N. (4) The maximum stress versus log $(N - N_0)$ is a straight line. To the extent that these assumptions are true for the particular alloy of concern, the analysis will be of help. To the extent that they are not true, the fatigue curve for very low probabilities will be quite misleading.

R68-13732 ASQC 822; 552
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
ABOUT THE APPRAISAL OF PROBABILITY OF DESTRUCTION DURING FATIGUE TESTS
M. N. Stepnov *In its* Structural Strength of Light Alloys and Steels 13 May 1966 p 35–40 refs
(N67-23525)

Proposed criterion of the accuracy of appraisals of the probability of destruction for normal distribution of properties during fatigue tests is shown to give a smaller systematic error than the Weibull formula. Considered criterion of accuracy and the appraisal of the probability of destruction may also be used for other forms of tests (static, prolonged static, and others). Author

Review: The author discusses plotting positions for cumulative probability. He asserts that the formula (i-1/2)/N is superior to the formula i/(N+1) where i is the i-th ordered failure and N is the total number of samples. While it is difficult to dispute the author's arithmetic, it should be kept in mind that if the sample is small, the scatter of the points around the expected line is very great regardless of the exact plotting position. One expects it to be very great because of the statistics and probabilities involved. If the exact plotting position is very important to you and your samples are small, you have troubles which will not be cured by any choice of plotting positions. For large samples, all plotting positions are very close, except perhaps on the tails, where again a great amount of scatter is to be expected. Therefore this paper will be more idly interesting than vitally informative. (The subject of plotting positions was also treated in the reports covered by R66-12870, R66-12871, and R66-12872.)

R68-13735 ASQC 824
Boeing Co., Seattle, Wash. Mathematics Research Lab.
RELATIONSHIPS AMONG SOME NOTIONS OF BIVARIATE DEPENDENCE
J. D. Esary and F. Proschan Jan. 1967 11 p refs *Its* Math Note No. 501
(DI-82-0597; AD-659612; N67-29062) CFSTI: HC $3.00/MF $0.65

A random variable T is left tail decreasing in a random variable S if P(T < or = t divides S < or = s) is non-increasing in s for all t, and right tail increasing in S if P(T > t divides S > s) is non-decreasing in s for all t. We show that either of these conditions implies that S,T are associated, i.e. Cov(f(S,T), g(S,T)) > or = 0 for all pairs of functions f,g which are non-decreasing in each argument. No two of these conditions for bivariate dependence are equivalent. Applications of these and other conditions for dependence in probability, statistics, and reliability theory are considered in Lehmann (1966) Ann. Math. Statist. and Esary, Proschan, and Walkup (1966) Boeing documents D1-82-0567, D1-82-0578. Author (TAB)

Review: This paper will be of interest mainly to those concerned with the theoretical aspects of reliability. The interrelationships among various recent concepts of dependence are fully explored. The applications of the dependence concepts are examined in [1] and the reports covered by R67-12969, R68-13554, and R68-13650.

Reference: [1] J. D. Esary, Frank Proschan, and D. W. Walkup, "A multivariate notion of association for general random variables," Mathematical Note No. 490, Mathematics Research Laboratory, Boeing Scientific Research Laboratories, Oct 66 (AD-643 976)

83 DESIGN

R68-13707 ASQC 830
DETERMINISTIC STRUCTURAL DESIGN CRITERIA BASED ON RELIABILITY CONCEPTS.
Innes Bouton, Donald J. Trent, and Halsey B. Chenoweth (North American Aviation, Inc., Space and Information Systems Div., Downey, Calif.).
AIAA Aerospace Sciences Meeting, 4th, Los Angeles June 27–29, 1966 p. 1–17.
(AIAA Paper-66-504; A66-33659) Members, $0.75; nonmembers, $1.50.

The essential elements of structural reliability are explored, and the relationship is shown between management decisions and achieved reliability levels. Practical procedures proposed for assuring that the necessary reliability decisions are made explicitly permit the development of structural design criteria that incorporate reliability concepts and also retain administrable deterministic features of current criteria. Attention is given to the causes of structural failure, the ingredients of structural reliability, and the deterministic procedures to assure reliability. Illustrative criteria situations are included, and a graph shows the growth of structural reliability from design through strength tests, load tests, and actual operation. M.W.R.

Review: This is a qualitative paper which discusses the *philosophy* of the design of the structure for an aerospace vehicle. The discussion is based on practical aspects of the problem and is well handled. Understanding the paper will require some knowledge of terminology such as limit- and ultimate-conditions, but in general there is a minimum of jargon. Many engineers may be misled by the title into expecting something they will not get, but regardless of that, the material in the paper is worthwhile and can be of benefit to both design engineers and program managers. The production of high reliability vehicles depends on an understanding of the philosophy involved.

R68-13708 ASQC 838; 414; 824
REDUNDANCY IN DECISION-MAKING SYSTEMS.
John G. Rau (North American Aviation, Inc., Anaheim, Calif.).
Operations Research, vol. 14, Jan.–Feb. 1966, p. 71–78.

Decision making systems are described that consist of *n* independent decision devices and include a single voting redundancy scheme. The components of the system are decision devices that make *yes* or *no* decisions, and system decision is determined by component decisions; however, the system is unable to determine whether the decision of each component is correct or incorrect. Redundancy is used to insure the probability that the system has made a correct decision; and it is shown how to determine the threshold level or the minumum number of votes that must be received to minimize the probability of the system making an incorrect decision. Examples of using this decision-making device are in an airborne sensor for scanning a target, a ground observation or electronic sensors to scan the sky for enemy targets, an electronic system that consists of a number of modules or subsystems that could possibly fail, and to ascertain whether targets appear in aerial photographs. Mathematical models for the decision function, properties of the decision function, and method for maximizing decision reliability are detailed. M.W.R.

Review: There is a logical difficulty in the author's assumption of a known probability P_Y that the event has occurred, since in a particular case the event either occurs ($P_Y=1$) or not ($P_Y=0$).

His analysis seems valid if P_Y represents a subjectively determined chance that the event will occur at any given future time. The determination and interpretation of such a chance is itself the difficult problem at the center of Bayesian statistics. Note also that the author implicitly assumes that errors of Types I and II are equally serious, since he solves the problem of minimizing the sum of the two error probabilities. An associated and seemingly interesting problem is minimization of a weighted average of the error probabilities, where the weight is proportional to the relative seriousness for a given type of error. Examples are provided relative to target detection, fault isolation, and aerial photograph analysis.

R68-13711 ASQC 831

OPTIMIZING SYSTEM EFFECTIVENESS OF MECHANICAL SYSTEMS.

S. R. Calabro (Aerospace Technology Corp., Newark, N. J.).
In: Proceedings of the 1966 Spring Seminar on Reliability Techniques...Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 31–36.

General configuration of a water injection system to provide reservoir pressure is described as part of a total systems effectiveness study conducted at a Venezuelan petroleum company. An electric-driven centrifugal pump, a de-aeration tower and surge tank, and a main pump package are part of the injection system powered by a 2,000 KVA transformer and control unit. The techniques used to gather and plot reliability data are illustrated, and an exponential distribution of time to failure was found from these data. Repair time distributions, on the other hand, followed a log normal distribution. Calculations are included of the uptime and downtime ratio using mean time between failure and mean time to repair. The method employed in determining the State System Effectiveness (SSE) is given, along with the method of summing the SSE's to obtain the actual system effectiveness. Methods of treating controlled and penalty costs in order to obtain optimum costs are illustrated; and a plot of optimum points for various assumptions indicates a trend toward lower costs and higher system effectiveness. M.W.R.

Review: This is a short paper which is an example of the calculation of system effectiveness from failure-time and maintenance-time data. Assuming that one is not interested in the actual installation, the example is useful as a case history. The fact that it is largely mechanical equipment is irrelevant except that it is interesting that the failure-time distribution was given reasonably well by the exponential. No indications of goodness of fit are shown for either the repair- or failure-time distributions, nor are these compared with other possible distributions for each. For example, if the repair times were represented reasonably well by logNormal, they probably were also represented reasonably well by Weibull. An interesting aspect of the calculation shows that the optimum system effectiveness has not yet been reached and cost could be lowered even more by increasing the times to failure or decreasing the repair times. The paper is useful as an example of how these calculations are made, but will not be useful as a general reference.

R68-13712 ASQC 831

MULTITHREADING DESIGN OF A RELIABLE AEROSPACE COMPUTER.

R. P. Hassett and E. H. Miller (Radio Corp. of America, Burlington, Mass.).
In: Proceedings of the 1966 Spring Seminar on Reliability Techniques...Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 37–48. 1 ref.

The organization of a reliable aerospace computer, based on a multithreading design in which a multiplicity of paths are available to perform the minimum data processing functions, is presented that utilizes active redundancy and a minimum of inactive redundant hardware. Other advantages of multithreading are maximum system effectiveness, multiple failure survival, demonstrable reliability, and deferred maintenance. The inverse proportionalities between speed/capacity and reliability are exploited in this computer operation; and the mathematical models used in four different configurations are detailed. Requirements for an aerospace computer are defined and analyzed to determine the storage capacity and speed required for the various data processing tasks. A study of tradeoff factors is reviewed, and an analysis is described to show how the concept of graceful degradation can be applied to a large-scale aerospace computer. M.W.R.

Review: This paper shows that inventiveness in creating a Figure-of-Merit (FOM) for a system, in breaking down the system into subsystems, and in ways of connecting the subsystems for partial mission success can provide big dividends. All such approaches, including the fairly common ones, are usually quite sensitive to the exact assumptions of FOM's and to values associated with partial failure and partial mission performance. This paper also illustrates the benefits to be gained from trying to throw off all constraints which are not actually there (as in the case of many puzzles whose solution lies in disregarding some possibly implicit restrictions). This paper is an example of the "work smarter, not harder" approach to improving reliability. One never knows what the boundaries really are until one has pushed up against them and found that he is actually pushed back. It must be emphasized again of course that the apparent improvement is a consequence of particular assumptions that are made. This is neither good nor bad it itself, but is essential to interpreting the paper and comparing it with other approaches.

R68-13715 ASQC 838; 431

REDUNDANCY APPLICATIONS TO THE APOLLO GUIDANCE COMPUTER AND MARKOVIAN MODELING FOR RELIABILITY ANALYSIS.

Donald M. Fradette (Raytheon Corp., Space and Information Systems Div., Sudbury, Mass.).
In: Proceedings of the 1966 Spring Seminar on Reliability Techniques...Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 71–85. 3 refs.

Techniques were evaluated for improving the reliability of the Apollo Guidance Computer (AGC) for use on long-duration manned missions. While the major emphasis in this paper is on the development of a Markovian mathematical model to evaluate mission reliability, attention is also given to the feasibility of operating dual AGC computers and to demonstrate that module replacement could be accomplished in a high humidity/salt environment. The dual computer concept is based on the conclusion that the overall mission can be divided into critical and noncritical phases; with launch and reentry considered critical, and coast period or orbit phase as noncritical. The feasibility of simultaneous

asynchronous computer operation with little degradation on computer outputs as well as the design of a computer module allowing repair during flight were demonstrated. The reliability model generated for the 90-day earth polar orbit Apollo Applications Program mission is detailed, for which a reliability of 0.999999 is apportioned during the critical phases of launch, polar orbit injection, orbit adjustment, and reentry. Reliability apportioned to the overall mission is 0.9994. M.W.R.

Review: This is a rather long paper for a case history and apparently presumes that some readers are interested in the details per se as opposed to being interested in the case as an example. The procedures are reasonably straightforward. The mathematics in the Appendix was not checked, but appears to be reasonable. Those who need to do similar computations will find considerable detail here to assist them, including printouts of some of the computer programs. The paper can be helpful to design and reliability engineers who are confronted with similar problems, but will be useful largely as a reference as opposed to tutorial material.

R68-13719 ASQC 837

ELECTROMECHANICAL ANALYSIS BY STATISTICS.

E. B. Haugen (North American Aviation, Inc., Space and Information Systems Div.).

In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, 1966, p. 31–49. 6 refs.

Statistical methods are used to optimize design of electromechanical devices, and a probabilistic approach to electromechanical design describes each parameter by a function instead of by a discrete value. The case of the design of a hingeless relay is used to illustrate the method, and the electromechanical design process is considered to involve three sets of random variables associated with the mechanical, magnetic, and electrical circuits. Spring design, voltage variate, and coil resistance variate are discussed; and current variate computation and reluctance variate estimation are illustrated. Detailed mathematical calculations are included. M.W.R.

Review: This paper presents a reasonably standard treatment of considering uncertainties in design equations. All variables are assumed to be statistically independent and the variations are assumed to be small (technically this would be stated that the formula is expanded in a Taylor series and all but the first-order terms are dropped). This is the usual method for calculating propagation of errors or uncertainties. While the author states that all the variates are assumed to be Normal, the only place where the Normality assumption is really used is in calculating a probability from what is often called the safety margin (mean {strength-stress} divided by standard deviation {strength-stress}). The formulas for propagation of tolerances, errors, and uncertainties are true regardless of Normality. The general requirement is that the variances be small (the formulas for the mean and variances of sums and differences are exact regardless of the distributions, the one for the mean does not even require statistical independence). Whether one likes the particular jargon being used and referenced in this text is probably a matter of personal taste since the subject was all well worked before Reliability came along (some of us wonder why it is necessary to introduce a new language to describe it). The paper does give a good example of how to use the technique and can be helpful to those who are trying to learn it. It is not universally applicable, but is usually better than not considering variations at all. Some of the arguments for this kind of statistical design vs. worst case tend to reduce to trivialities in practice since the total spread chosen for the components in either case tends to be about the same especially when Normality is considered and very high reliabilities are desired. Some of the explanations in the paper are overly complicated and it may be difficult for the beginner to figure out what is going on.

R68-13725 ASQC 838

ON COLD REDUNDANCY WITH RESTORATION.

A. F. Zubova

(Avtomatika i Telemekhanika, vol. 26, Oct. 1965, p. 1800–1808.) *Automation and Remote Control,* vol. 26, July, 1965, p. 1738–1745. 6 refs. Translation.

(A66-28546)

A method is presented for determining the probability of survival of a system consisting of one active and m redundant elements, with arbitrary distribution functions of the no-failure time of the operating time and the restoration time. This method is referred to as cold redundancy with restoration, and the elements of the system are either equireliable or nonequireliable. In the case of duplication, the effect of probability survival or restoration is directly proportional to the ratio of the mean no-failure operating time of the nonredundant element to the mean time of the restoration. Detailed equations are presented, and two examples are included to show how the probability of survival can be determined for a restorable system with cold redundancy and either equireliable or nonequireliable elements. M.W.R.

Review: This is a theoretical paper which deals with the problem of redundancy. The redundant elements are presumed to have a zero hazard rate while not in use and any element after failing is presumed to be repaired according to an arbitrary time distribution. The author takes some special cases first and then treats the general case by analogy. Not all the mathematics was checked but it appears to be competent. The solution is obtained in an integral equation, which cannot be solved explicitly unless the forms of the various functions are given. The author works out some examples. This paper is another contribution to the mathematical theory of reliability, albeit a very specialized contribution.

R68-13727 ASQC 838

PROVIDING REDUNDANCY TO DEVICES OPERATING CYCLE-BY-CYCLE.

L. B. Venchkovskii

(Avtomatika i Telemekhanika, vol. 26, Nov. 1965, p. 2026–2031.) *Automation and Remote Control,* vol. 26, July, 1965, p. 1952–1958. 3 refs. Translation.

Various redundancy methods are compared for cycle-by-cycle operating devices in radioelectronics, particularly those used for remote control. Reliability is evaluated with respect to the catastrophic failure of elements; and it is assumed that the nonredundant system contains a chain of monotypic equally reliable elements whose reliability is described by an exponential function. Element-by-element redundancy is discussed as are common redundant elements for all the elements of a system. Redundant elements connected to the operating element are also considered. It is concluded that the cycle-by-cycle character of the studied system operation permits the construction of reliable systems with relatively little redundance. When there is a linear dependence of element lifetime on size of relative redundancy, the increase in mean system lifetime is proportional to the number of backup elements. As the number of cycles in a system increases, there is an increase in system reliability for the same values of relative redundancy. M.W.R.

Review: This is a theoretical paper which analyzes certain kinds of redundancy. It is presumed that all elements have a constant hazard rate, and that there is no repair. Several kinds of redundancies of basic identical elements are considered, among them series-parallel. The figure of merit is mean-time-to-failure which has disadvantages if the time of operation is short compared to this number; in that case hazard rate is a better indicator. Not all the mathematics was checked, but it appears to be competent. The paper will be of use largely to theorists. Design engineers would find any of the results too difficult to apply. It is likely that similar material appears in the American reliability literature, although this translation is not too difficult to read. A consideration in the text is to have the hazard rate of each unit decrease as active redundant units are added. The cycle-by-cycle character of operation is not described very clearly; if all the elements are identical (as seems to be presumed) it is difficult to see the nature of using but one of them, a different one each time, plus using all of the others as back-ups at that particular time. Those theorists who are trying to stay abreast of all the special Reliability cases being analyzed will want to look at this paper.

R68-13736 ASQC 835
HIGH-DENSITY PACKAGING TECHNIQUE FOR COMPLEX AEROSPACE ELECTRONICS.
David S. Walker (Sperry Rand Corp., Sperry Gyroscope Co., Great Neck, N. Y.).
Space Congress on the Challenge of the 1970's, 4th, Session 6—Value Analysis Quality Control and Reliability, Cocoa Beach, Fla., Apr. 3–6, 1967, 18 p 6 refs.
(A67-36603)

Description of a standardized technique for producing reliable, long-life, electronics equipment directly exposed to the environment of outer space. The first space application of this technique was the Inertial Reference Unit for the Lunar Orbiter. The design and manufacturing procedures used to achieve an electronics packaging density of 15 parts/in.^{3} with standard Hi-Rel parts are described. Quick reaction time for prototypes and production, lightweight structural integrity, and good heat transfer characteristics are additional features resulting from the technique. IAA

Review: A quite comprehensive description is given of the design and manufacturing procedures used to achieve an electronic packaging density of 15 parts per cubic inch with standard Hi–Rel parts. It will be of interest to those concerned with the production of reliable electronic equipment for spacecraft use. While the specifics in the paper have reference to the Inertial Reference Unit for the NASA Lunar Orbiter, the principles and techniques clearly have applicability to other electronics equipment. The paper serves to illustrate some of the tasks which must be accomplished in order to get a reliable system into orbit. Prominent features of the approach are the use of approved components of proven reliability and conservative manufacturing techniques.

R68-13740 ASQC 831; 837; 844
NO DESIGN CHECKMATES . . . COMPUTER AIDED CIRCUIT DESIGN.
D. G. Mark (Motorola, Inc., Reliability and Components Group). Reprinted from *Motorola Engineering Bulletin,* Vol. 14, 1966 p. 24–35 7 refs.

A Design for Reliability, or a computer-aided design technique, uses circuit design requirements as input and receives schematic diagrams and production prototypes as output from the computer. Originated during the Terrier missile program, the Design for Reliability concept is applied to the development of electronic circuits and systems; and a typical design example is shown along with the analysis and simulation and derivation of the necessary mathematical model. Statistical analyses required here and for the optimization of the design are described; and a summary is included of results of moment tolerance analysis for a signal processing amplifier. In addition to the moment analysis, the Monte Carlo program and empirical methods are considered. M.W.R.

Review: The reliability analyst and designer concerned with practical application of parameter variation analysis techniques as a design tool will find this paper very worthwhile reading. Whereas the specific techniques such as worst-case analysis, sensitivity analysis, and the moments methods are not described in detail (elementary descriptions of these can be found in papers covered by R66-12492 and R67-13326), their application is discussed in a very easy-to-understand manner in conjunction with a circuit design problem. The emphasis is on analytical assessment of performance during the paper stage of design. It is gathered from the discussion that the techniques are implemented in very simple form; for example, there was no mention of using parameter correlations or second and higher order derivatives in variability calculations. Even though this aspect was not discussed, experience has generally indicated that such requirements are not necessary for most circuit design problems. There seems to be an inference throughout most of the discussion that the final design can be achieved totally in this manner. There is no indication of how closely the performance of actual circuits fabricated according to the paper design conforms to the analytical results, nor how much additional effort is required to achieve the final design. The author does recognize, however, that not all situations are equally amenable to this approach, and some require more reliance on empirical methods. Analytical studies can, when applied with discretion, aid the designer considerably at times in resolving certain design problems. This is well illustrated in the paper. The procedures are not too much of a cookbook nature, but leave room for good engineering judgment. The results of the analysis are in a form useful to the engineer for making design decisions. Use of parameter variation analysis techniques in the manner described in this paper is clearly not just "analysis for analysis' sake." The use of parameter variation analysis techniques as routine aids to design are rapidly becoming commonplace. As illustrated in this paper, the techniques can be implemented conveniently with computers and used in a supplementary role with automated circuit analysis programs in a well-coordinated computer-aided design effort. More and better education of the engineer in the concepts, application, and benefit of these advanced methods is needed; this paper is a worthy contribution to this cause.

84 METHODS OF RELIABILITY ANALYSIS

R68-13713 ASQC 844; 775
INFRARED: NEW APPROACH TO THERMAL MEASUREMENT FOR RELIABILITY.
Riccardo Vanzetti (Raytheon Co., Wayland, Mass.) and Melvin Mark (Northeastern University, Boston, Mass.).
In: Proceedings of the 1966 Spring Seminar on Reliability Techniques...Today and Tomorrow! Bedford, Mass., Apr. 14, 1966. Seminar sponsored by Institute of Electrical and Electronics Engineers, Reliability Chapter, Boston Section and Air Force Systems Command, Electronic Systems Division, Hanscom Field. Compiled and edited by RCA, Aerospace Systems Div., Burlington, Mass. Newton, Mass., IEEE, Inc., 1966, p. 49–62.

Infrared techniques for quality assurance are outlined; and the key steps from initial design evaluation through reliability improvement, inspection, test, troubleshooting, failure analysis, and service and maintenance are detailed in terms of applications to electrically energized components, assemblies, and systems. The conventional reliability calculation method and its dependence upon ambient temperature is discarded in favor of a maximum component temperature concept, and temperature measurement by infrared techniques is discussed along with various scanning systems and display techniques. The concept of a well-defined infrared profile typical of every failure is advanced, and the statistical approach versus the actual assessment of replacement needs is considered. M.W.R.

Review: This is a tutorial paper and is related to several such that the first author has participated in producing (see, for example, R63-10993, R65-11991, R65-12126, as well as the volumes covered by R67-13151 and R67-13234—in fact, this very paper appears in Section B-4 of the latter volume). The paper is a good one; it is certainly an enthusiastic one. It describes well enough for the newcomer how infrared analysis works. Infrared testing is an area which will undoubtedly make important contributions to both electronic and mechanical reliability and in spite of the slight unbalance of enthusiasm (it will be wise to locate another reference which gives some of the difficulties encountered with infrared testing) will be a good introduction to this field for design, production, and reliability engineers. It does not consider any of the infrared theory but is presented in an electrical engineering context. The first author in a private communication has pointed out that the most important disclosure of the paper is the formulation of a novel approach for more precise determination of the failure ratio for electronic components. He goes on to comment as follows. "This novel approach is based on the temperature measurement of every component-part while it operates in its normal electrical mode. This temperature, in turn, is used to determine the failure ratio of the component by means of new reliability charts correlating failure ratio to component temperature. This is a radical departure from the time-honored approach of using reliability charts correlating failure ratio to the temperature of the ambient where the components operate. It is obvious that the new approach will yield much more realistic reliability data than has ever been possible with the system in use so far."

R68-13716 ASQC 844; 780

FAILURE FREQUENCY ADJUSTMENT FACTORS (K_e) FOR VARIOUS ENVIRONMENTAL CONDITIONS.

Logan Haycraft, Jr. (Boeing Co., Space Div., Seattle, Wash.).
In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section, and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, 1966, p. 1–7

Derivation of failure frequency adjustment factors (K_e) is described for environmental conditions that are considered more realistic than those currently used in the aerospace industry. A system is described that permits the user to accurately specify the expected environmental conditions for a wide variety of type parts in order to generate K_e factors unique to any combination of environment and part type. The method employed groups parts into the categories of mechanical, electromechanical, electrical, batteries, solid state, and ordnance devices; and the eight main environmental categories considered are temperature, ambient pressure, relative humidity, ionizing radiation, vibration, acceleration, shock, and acoustic noise. Each of the environmental conditions is divided into several cells representing gradually increasing severity, and a tentative set of multipliers is established for each part family with respect to a useful range of each of the environmental conditions. Values of K_e obtained from these multipliers compared favorably with actual test or operational failure data. M.W.R.

Review: This paper is an earlier version of the one covered by R67-13414; the later paper should be consulted by those interested in this topic. The review for that paper applies to this one also.

R68-13723 ASQC 844; 541; 824

ESTIMATION OF DESIGN ALLOWABLES BY USE OF THE LOGISTIC DISTRIBUTION FUNCTION AND REGRESSION ANALYSIS.

N. Marcus Peterson (North American Aviation, Inc., Space and Information Systems Div.).
In: Industrial Progress through Reliability; Annual West Coast Reliability Symposium, 7th, Los Angeles, May 14, 1966. Symposium sponsored by American Society for Quality Control, Reliability Division, Los Angeles Section and University of Southern California, School of Engineering. North Hollywood, Calif., Western Periodicals Co., May 14, 1966, p. 139–154. 2 refs.

The strength of 2014-T6 aluminum is analyzed to determine variation in tensile strength and to predict quantitative design functional relationships; and the logistic distribution function was used to determine the design allowables for 2014-T6 aluminum for structural purposes in flight missiles. An analysis of variance was applied to the data obtained from the testing of 15 specimens in the longitudinal and transverse directions. Variation between runs of parent material was found to be highly significant, but differences between longitudinal and transverse tests were slight. The distribution of ultimate tensile strength of the material was obtained to estimate the minimum design limits. M.W.R.

Review: This is a specialized paper which attempts to show how to fit the Logistics distribution function to some aluminum strength data. Two of the author's previous papers are given as references on the Logistics function. The function itself is not explicitly defined anywhere in the text; since most engineers will not know what it is, this is a great disadvantage. The discussion is given in terms of aircraft terminology, e.g., design allowables, "A" values, and functional-threshold—the meanings of which are not clearly defined for non-aircraft engineers. It is not too clear why the author does everything he does and much of the reasoning has to be inferred from the arithmetic. Most people who are trying to learn something from the paper about either the particular aluminum itself or the method of fitting the curves to the strength data, and who are not familiar with those subjects already, will get lost in the details. Some of the difficulties are the following. (1) The methods chosen for estimating the parameters of the Logistics' distribution and the "A" values are not justified by the author in any statistical sense. (2) In the analytical method he has not considered the weighting of the original points that occurs because of his analysis. (3) He uses the sample mean to estimate one of the parameters of the distribution and it is not clear that it is either a good or a "best" estimate. (The maximum likelihood solution where the strength data are considered independent and of the same weight does not yield explicit estimates for either of the parameters of the Logistics distribution.) (4) His technique, using least-squares fitting of the cumulative distribution, applies the least-squares equations in a blind manner. The data are not statistically independent because they are ordered. There is no way to calculate the 95% confidence required for the "A" value. (5) It is not even clear what he means by two runs of the parent metal—whether they were just different batches from the same heat or two completely independent samples, or something else, is not made clear. In short, there is little of value in this paper.

R68-13733 ASQC 844
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
FOR DETERMINATION OF PROBABILITY OF FATIGUE BREAKDOWN DURING RANDOM STATIONARY LOADING
A. S. Isayev *In its* Structural Strength of Light Alloys and Steels 13 May 1967 p 41–51 refs
(N67-23526)

A method is proposed for calculating fatigue damage during the action of a stationary random load which is sufficiently simple, since it is based on the hypothesis about linear accumulation of damage. It considers the inconstancy of the coefficient of asymmetry of a cycle in a random load, which makes it possible to renounce the frequently taken assumption about the fact that on the average the load is changed with respect to the symmetric cycle. This method permits one to consider scattering of sample properties and to calculate the probability of fatigue breakdown according to time. Author

Review: This is another method of estimating the damage due to random fatigue loading. It uses linear cumulation of fatigue damage and makes the assumption that the probability density function of N is the same for the reduced variable $(N-\mu)/\sigma$ no matter what the load (N is the number of cycles, μ the mean of N, and σ the standard deviation of N). A method is introduced for breaking the random loading into cycles. It appears that the author wishes to account for the mean value of the load by fitting some arbitrary linear function (six unknown parameters) to the data. The reading of the paper is tedious in part due to the stilted language of the translation and perhaps in part because every phase of the derivation is treated in detail regardless of its simplicity. The author does not give actual cases of use of the method. The paper will be of no value to designers, but some theorist interested in cumulative damage and random loading may wish to see if he can figure out what it really says.

R68-13734 ASQC 844
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
EXPERIMENTAL INVESTIGATION OF FATIGUE FOR RANDOM LOADING
A. S. Isayev *In its* Structural Strength of Light Alloys and Steels 13 May 1966 p 53–68 refs
(N67-23527)

Present methods of calculated determination of endurance and tests of structural elements which are subjected to random loading, do not consider a number of factors characterizing the change of a load according to time, and are not checked experimentally in conditions of loading which are close to actual. An installation is described that permits modelling, in laboratory conditions, of random stationary loading which possesses an ergodic property, with a different spectral density, dispersions, and mathematical expectations. On the installation, the influence of different statistical characteristics of loading can be investigated separately. The experimentally produced values of the coefficient of equivalence connect the mean square deviation of a random load with the amplitude of an equivalent harmonic load. The development of a fatigue crack during random and harmonic loading (for a selected type of samples) carries a different character in principle. With the help of developed methods of tests and equipment, the correctness of any hypothesis of accumulation of damages in conditions of random loading can be checked. Author

Review: This paper considers random loading with a stationary Gaussian distribution. Equivalent constant stress tests were derived by requiring that the number of maxima in each (the random and constant stress) be the same. The author takes considerable space to describe the random signal generator, which rather than shaping a noise source, sums a great many sine waves. He asserts that his results support the theory, but that the scatter makes this conclusion uncertain. This paper will be of value only to some theorist interested in pursuing this subject in detail. It will be of no use to design engineers.

R68-13738 ASQC 844
STATIC ELECTRICITY AND TRANSISTOR FAILURES.
Donald Wright and John E. Johnson (Radiation, Inc., Palm Bay, Fla.).
Space Congress on the Challenge of the 1970's, 4th, Session 6—Value Analysis Quality Control and Reliability, Cocoa Beach, Fla., Apr. 3–6, 1967, 11 p.
(A67-36608)

Experimental investigation of the isolation and solution of an electrostatic charge problem. Evidence is presented, through a case history, that static electricity is a potential reliability problem in the production of electronic equipment containing small-geometry semiconductors. The problem occurred specifically during the production of a polyurethane-foam-encapsulated electronic assembly After foam removal, it was frequently found that transistors, known to be good prior to defoaming, were defective. An investigation demonstrated that many of the transistors failed as a result of discharging static electricity through the transistor junction. In an investigation of the defoaming process, the cause of transistor failures was convincingly isolated and attributed to the effects of static electricity. IAA

Review: A case-history study is presented, demonstrating that the effects of static electricity can cause transistor failures. The failures described occurred during a de-encapsulation (defoaming) process performed to facilitate trouble-shooting. The failure mechanism appeared to be a breakdown of the silicon dioxide passivation layer. The experiment performed to determine if the static potentials observed were the cause of the transistor failures is described in reasonable detail, and several photographs are included. The paper serves quite well its purpose of bringing to the attention of industry the problems which can result from the existence of static potentials in the fabrication of state-of-the-art electronic equipment. As the authors have indicated, little information is available in the literature on this failure mechanism. They have also called attention to the fact that further investigations are needed in order to understand fully the extent of the problems which may be caused by static electricity.

R68-13739 ASQC 844
THE PERFORMANCE OF UNMANNED SPACECRAFT IN SPACE.
J. B. Rittenhouse (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Materials Sciences Laboratory and Research Laboratories, Palo Alto, Calif.).
Space Congress on the Challenge of the 1970's, 4th, Session 6—Value Analysis Quality Control and Reliability, Cocoa Beach, Fla. Apr. 3–6, 1967 7 p 10 refs.
(A67-36573)

Analysis of the lifetime of several U.S. scientific, weather, and navigational spacecraft transmitting useful data. A suitable sample of spacecraft launched from January 1958 to January 1967 is selected to extrapolate the lifetimes of future spacecraft to the 1970 decade. It is shown, for example, that in a chosen sample of spacecraft launched in the period ending in 1967, 47 were still operating. Of 15 selected spacecraft launched in 1965, 13 were

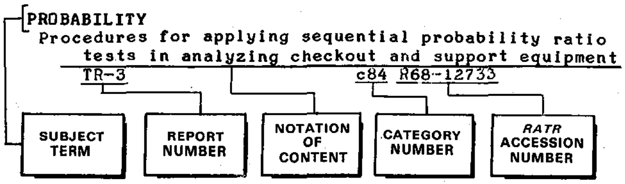
still operating. It is noted that, as the mission objectives for unmanned spacecraft become more complex with required longer lifetimes, the spacecraft to perform these objectives become more complex. However, longer mission lifetime is now and will continue to be a design requirement. The manner in which some of the recently launched spacecraft have performed and the implications of this behavior on future designs and the selection of their construction materials are discussed. IAA

Review: This is a concise and rather general description of the problems associated with the assuring of high reliability for spacecraft in which long lifetimes are required. The importance of recognizing that reliability is a *defined* term and of properly relating mission objectives to reliability criteria are emphasized. Appropriate reliability strategies are outlined. Brief reference is made to problems in the reliability of mechanical components or subsystems, and to the demonstration of achieved reliability in complex long-life systems. Data are given on the lifetimes of some selected U. S. unclassified scientific, weather, and navigational spacecraft. Some illustrative figures are included. The paper will be useful chiefly to those who want to take a quick look at the problems of insuring that unmanned spacecraft operate normally under the various expected conditions which they will encounter. The discussion is keyed to ten references which will be useful to those who wish to look into some of these matters in more detail.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 4

Typical Subject Index Listing



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A

B

C

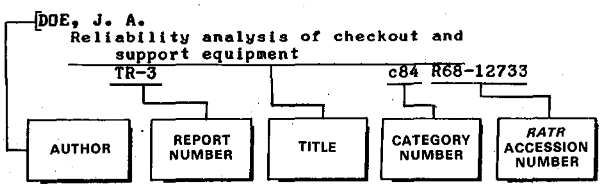
T

U

PERSONAL AUTHOR INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 4

Typical Personal Author Index Listing



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REPORT AND CODE INDEX

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB, STAR,* and *IAA,* respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 4

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Reliability Abstracts and Technical Reviews

MAY 1968

Volume 8
Number 5

R68-13742—R68-13790

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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EXAMPLES OF CITATIONS IN *RATR*

		ASQC CODES
RATR ACCESSION NUMBER	R68-12733 ASQC 844; 413	CORPORATE SOURCE
TITLE	General Equipment Company, Banville, Calif.	
	RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT	PUBLICATION DATE
AUTHOR	John A. Doe 23 Sep. 1966 27 p refs	
CONTRACT OR GRANT	(Contract NAS15-13411)	*TAB* AND *STAR* ACCESSION NUMBERS
	(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65	
REPORT NUMBER		SALES AGENCY AND PRICE

RATR ACCESSION NUMBER	R68-12739 ASQC 814	ASQC CODE
	SEMICONDUCTOR RELIABILITY	
TITLE	Joseph A. Smith (Eastern University, Arlington, Penn.)	AUTHOR AND AFFILIATION
	Electric Journal, vol. 8, Apr. 1966, p 478–492.	
JOURNAL REFERENCE	(A68-12569)	*IAA* ACCESSION NUMBER

RATR ACCESSION NUMBER	R68-12765 ASQC 773; 221; 823	ASQC CODES
TITLE	**TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES**	
	Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)	AUTHORS AND AFFILIATIONS
CONFERENCE OR SYMPOSIUM REFERENCE	*Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p*	
	Available from Assoc. of Reliability Eng., New York: $1.00	AVAILABILITY AND PRICE
IAA ACCESSION NUMBER	(A68-12407)	

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A Monthly Publication

of the National Aeronautics and Space Administration

May 1968

80 RELIABILITY

R68-13763 ASQC 800
AUTOMOTIVE RELIABILITY: TROUBLE OR TRIUMPH—PARTS I AND II.
Quality Progress, vol. 1, Jan. and Feb. 1968, p. 18–21, 12–13.

Development of reliability tools and testing procedures are discussed in a two-part article that presents some actual experiences of the automotive industry. Both component and product reliability are discussed, and the need for increased use of computers for processing reliability data is emphasized. While built-in quality and safety is a must, perfection is considered a fantastic idea for automobile manufacturers. It is so-called inherent reliability that automotive engineers have developed, according to this overview of progress and problems in automotive reliability. M.W.R.

Review: This is a very qualitative paper. A large portion of it consists of easy-reading condensed history of a few automobile manufacturers. The part of most concern to reliability engineers is fairly short and has to do with the meaning of the word "reliability" and perhaps of the term "inherent reliability." As stated before in these reviews, the term "inherent reliability" is so vague as to be meaningless. Many authors, including some of the automotive executives quoted in this article, seem to be implying the following definition of inherent reliability: the reliability calculated using only certain kinds of failures, viz., those which an aggressive, alert, imaginative designer could not blame on someone else. In defining reliability as a probability, there exists the ambiguity inherent in the usual definition as to whether or not it is a conditional probability, the condition being that the equipment is in perfect shape at $t=0$. If this condition is added, there then exists the controversy about what is meant by perfect shape, for example, whether all parts must just be working or whether all parts must have no obvious defects, etc. There is some indication that some automotive executives wish to start the quality versus reliability fight again—something which most engineers gave up a long time ago as a waste of time and effort. Thus, while an article with this title might have contained useful information or philosophy for aerospace reliability engineers, this particular paper does not.

R68-13766 ASQC 800
HINTS AND KINKS.
Paul Gottfried (Booz-Allen Applied Research, Inc.).
IEEE Newsletter, Reliability Group, vol. 13, Jan. 1968, p. 4.

Management, methods, and mathematics aspects of reliability are described and their interrelationships are noted. As in other fields, management in reliability is concerned with keeping requirements and resources under control. The methods are the engineering procedures that determine equipment life and integrity, while the mathematics aspect provides the means of estimating the consequences of implementing specific methods and, perhaps, management decisions. M.W.R.

Review: These notes which appear from time to time are more valuable than their casual format and newsletter appearance would indicate. The author specializes in taking a reasonable, practical approach to some of the difficult facets of reliability. This note deals with defining the areas of and relationships between management, methods, and mathematics of reliability. One point that will rightly appeal to the readers of this note is that the three functions, as they are defined for reliability, are shown to be similar to the same functions in other fields. Reliability is not set apart as being something unique, but managers and engineers have the same kinds of duties in reliability as they have elsewhere. This paper is short, pertinent, good, and recommended for reading, especially for those inclined to argue about such things.

R68-13778 ASQC 800
RELIABILITY ISN'T WHAT IT USED TO BE—IT NEVER WAS.
George E. Kelm (American Telephone and Telegraph Co., Automotive Group, New York, N. Y.).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 81–85.

The vehicle user's viewpoint on automotive reliability is presented by an industrial user with a fleet of 123,000 vehicles. New vehicle pre-delivery service inspection is discussed, and defects found during pre-delivery inspections of 1966–67 vehicles are shown graphically. An appendix lists some specific defects found in new vehicles. M.W.R.

Review: This paper is of interest to aerospace reliability engineers because (1) they are consumers of automobiles, (2) it throws a different light on papers about automotive reliability presented at the Symposium by the manufacturers, and (3) because of (2), it helps them read *any* glowing reliability paper with somewhat more skepticism than might otherwise be the case. When

a paper is presented at a symposium by a company employee; any trade-off between company image and the unvarnished truth is made in the direction which will enhance the image of those who are paying the bill. This is why so many of the management-oriented papers which deal with the wonderful organization of "our company's" reliability program are not really worth much. They do not show what happens under the daily stresses and strains that tend to tear apart the best of intentions. So this article is worth reading. Just remember that a customer probably could write the same kind of story about your product.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13748 ASQC 813; 770; 833
THE MARINER MARS PARTS SCREENING PROGRAM.
W. H. Lockyear (California Institute of Technology, Jet Propulsion Laboratory, Electronic Parts Engineering Section, Pasadena, Calif.).
In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 4–2 to 4–19.
(A66-42089)

Discussion of the Mariner 1964 screening program, including the philosophy, program implementation, screening results and conclusions. The general screening test requirements, the general acceptance testing requirements, and the reject rates of parts used in the various Mariner spacecraft are tabulated. Also tabulated are the part hour and failure summary and the failure rates of Mariner 4. The Mariner Mars electronic parts screening program is thought to have been a significant factor in the flight success of the spacecraft. IAA

Review: This paper serves a two-fold purpose—it can help convince those who do not believe in screening that screening is in fact a good idea, and it helps to erase the unfavorable memory of earlier spacecraft failures associated with the author's institution. It accomplishes both purposes quite well. No mention is made of the problem of how many "good" parts (i.e., those which would have performed well in the spacecraft) are rejected along with the bad ones and the table involving estimated failure rates has a discussion that is somewhat loose; both of these are minor points in the context of the successful spaceflight of Mariner IV.

R68-13749 ASQC 813; 770; 833
APOLLO SPACECRAFT PARTS SCREENING PROGRAMS.
M. W. Steinthal (NASA. Manned Spacecraft Center, Houston, Tex.), and G. T. Lester (General Electric Co., Missile and Space Div., Apollo Support Dept., Houston, Tex.).
In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 5–2 to 5–4.
(A66-42090)

Description of the Apollo spacecraft parts screening programs designed to insure mission success. Examples are shown which indicate that the reliability required for mission success depends upon the development of effective parts screening programs. Types of screens discussed include general acceptance, catastrophic failure, drift failure, extended performance, and application screens. IAA

Review: This is a brief summary which lists the major topics involved in the screening procedure and gives a short discussion of each one. An example of the cost due to a poor and unscreened part illustrates the problems one can run into. Generally speaking, the amount of screening, both as to the fraction of parts coming under it and the intensiveness for each part, depend on the cost of failures versus the costs of the screening. For most industrial and military projects, at least some screening must be done, since otherwise the product is likely to be very poor. This situation is just the same for integrated circuits as it was for discrete components.

R68-13756 ASQC 815
IMPROVING YOUR MICROELECTRONIC SPECIFICATIONS.
Timothy Da Silva (Signetics Corp., Sunnyvale, Calif.).
In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 26-2 to 26-5.

Procurement specifications for microelectronic circuits are considered in terms of the contributions that can be made by the circuit supplier and the cooperative efforts between supplier and user. Manufacturing controls, pre-production screens, specification of acceptance tests, and choice of sampling plans are discussed. Effectiveness of the test series and costs are noted as the two major considerations in the evaluation of a reliability screen series; and attention is given to the circuit failure mechanisms and cutting environmental costs. M.W.R.

Review: This is the kind of paper whose general philosophy can last much longer than the specific details. The requirements for specifications of microelectronic devices change appreciably as the technology matures and as the marketplace becomes more hectic. The kinds of points the author is making are good. However, the general subject can be one of the biggest headaches for a small user. He is caught on the horns of the dilemma of specifications being expensive and a lack of specifications flooding him with poor quality. There is a school of thought that says one should buy commercial devices only to the manufacturer's specification and then screen them (or make the manufacturer screen them), but introduce no further specifications back into the manufacturer's processing. If you are a big enough user, the manufacturer will virtually set up your own production line for you and there is less of a problem. When the paper was presented, it provided more valuable information than it contains now as a reference.

R68-13757 ASQC 814; 844
QUALITY FAILURE COST ANALYSIS.
D. C. Stone (Philips Electrical Ltd., Croydon, Surrey, England).
(Joint I.E.R.E.-Prod. E.-I.E.E. Conf. on the Integration of Design and Production in the Electronics Industry, Nottingham, England, July 10–13, 1967). The Radio and Electronic Engineer, vol. 34, Dec. 1967, p. 335–344.

A method is presented for organizing production and inspection, fault information analysis, and costing to determine and control quality failure costs arising during final assembly and testing of television receivers. Reject percentages as well as costs resulting

from manufacturing faults are determined, main causes of failures are located, and the amount of expenditures for improving quality without increasing product price is derived. A correlation between assembly failures in the factory and service costs in the field is indicated in a chart that summarizes defects found in 100 sets. Inspection plan, panel viewing, and fault tracing are discussed as sources of faults information; and the advantages of producing faults information in standardized form are noted. Both costing of faults and computing costs are considered. M.W.R.

Review: This paper deals with locating and analyzing faults in a television receiver. It is applicable to quality/reliability problems in any electronic product of similar or less complexity. The system as described appears reasonable and enough detail is given so that a person unfamiliar with this type of operation can learn a lot from reading the paper. Those who work for large companies or ones with aggressive quality/reliability groups will undoubtedly (we hope) pass beyond the level of sophistication of this paper. Some of the terms, such as Pareto analysis, may not be familiar in this country. This analysis apparently involves the listing of items in the order of their frequency of occurrence, so that the things causing the most trouble can be isolated easily. The paper will be of use to quality or reliability engineers and management rather than design engineers.

R68-13764 ASQC 810; 770; 814

SYSTEMS TESTING—AN AEROSPACE MANAGEMENT VIEW.

R. W. Johnson (NASA, Office of Manned Space Flight, Advanced Lunar Research Studies Group, Washington, D. C.).

Materials Research and Standards, vol. 8, Jan. 1968, p. 8–11. (A68-15587)

Discussion of the assets and liabilities of systems testing in a simulated space environment. Two approaches to simulation testing emphasizing either test and evaluation of component and subassemblies or whole-systems tests designed to evaluate the complex interactions between major assemblies and subsystems are evaluated and compared. Factors such as reliability, design lifetime, development, schedules, and, in the case of manned spacecraft, astronaut safety are used as the criteria for evaluation. IAA

Review: This paper is not "just another management paper" even though the title might imply it. The author is concerned with the cost of testing and with the allocation of testing to subsystems versus systems, in order to provide the most information for the least cost. The author does a good job of showing the conflicting interest and philosophies that management has in this area. He does not attempt to say which one of these is always better but he does ably point out the places where each has its advantages and disadvantages.

R68-13770 ASQC 810

RELIABILITY MANAGEMENT UNDER AUTOMATION.

J. V. Hunt (Westinghouse Electric Co., Lamp Div., Bloomfield, N. J.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 15–19. 3 refs.

The system used by a mass production industry to assure reliability of its products (light bulbs) is discussed, and the need to coordinate and carefully plan the reliability and quality control functions is stressed. Product reliability committees perform the necessary coordinating functions; and such a committee might be composed of an engineering person as chairman as well as representatives from manufacturing, marketing, purchasing, equipment engineering, and reliability. Overall policy of the reliability program is noted, and various tools to implement the program are discussed. The design review is considered the most effective quality improvement tool, and in this phase engineering design is systematically studied by persons not directly associated with product development. Quality control, physical quality of the product, electrical characteristics, and audit inspections used to assure reliability are described. M.W.R.

Review: The outstanding feature of this paper is the orientation to commercial products (light bulbs in this case). The paper presents an interesting narrative description of one organization's approach to reliability and quality control and will thus be of primary interest to management personnel. Users of light bulbs are often discontented because of the seemingly-shorter lives of bulbs than manufacturers' advertising claims indicate. However, if the practices described in the paper are done well, then the manufacturer is conscientiously striving for a reliable product and is not in error in making the claims he makes about bulb life. Unfortunately, as pointed out in the paper, the electrical operating conditions over which the bulb manufacturer has essentially no control, have a large bearing on bulb life. The major tasks comprising the program described are essentially the same (at least in name) as many of those found in any government-sponsored program for procurement of high-reliability products.

R68-13771 ASQC 816

IMPROVE RELIABILITY THROUGH VENDOR ASSURANCE.

Andrew J. May (Singer Co., Elizabeth, N. J.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 21–30. 5 refs.

Communication between vendor and vendee is emphasized as a means of improving overall reliability, and a system for total vendor assurance is outlined. Vendor selection is the basic block of the system; and vendor survey, financial evaluation and past performance are mentioned in this regard. The need for product evaluation, a pre-award discussion of requirements, and a purchase order package including all these requirements are discussed. A supplier handbook that contains all quality control policies, procedures, and practices is suggested to provide the necessary guidelines and avoid misunderstandings. A total vendor assurance program should also provide the vendors with inspection results, develop effective corrective action, and establish a vendor rating system. M.W.R.

Review: Vendor assurance and control is just one important aspect of the reliability and quality assurance function. This paper describes briefly a concept of a system, called TOTAL VENDOR ASSURANCE, for achieving the necessary control. Good two-way communication is rightly recognized as an important ingredient of the vendor–vendee relationship, and the paper views the elements of the system as communication channels. The system described would typically be new for commercial products. However, the tasks are mainly those already done in any conventional, well-managed government-sponsored program (c.f. NASA Quality Publication NPC 200-2, Quality Program Provisions for Space System Contractors). This paper can serve to provide a quick perspective to a newcomer. Experienced reliability and quality control personnel may benefit by reviewing it to identify missing elements in their own programs.

R68-13772 ASQC 810; 831
THE WSEIAC CONCEPT—ITS APPLICABILITY/VALIDITY.
Jerome Klion (Rome Air Development Center, Griffiss AFB, N. Y.).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control New York, IEEE, Inc., 1968, p. 31–37.

Validity, applicability, and practicability were determined for a system effectiveness evaluation concept developed by the Weapon System Effectiveness Industry Advisory Committee (WSEIAC) for various Air Force systems and subsystems. Since validity implies that the system and mission can be defined, the information required for estimating the operability and performance characteristics of the system is economically available. An infrared Search and Track System (IRSTS) was evaluated in three epochs of its life with the WSEIAC technique; and results showed reasonable progressive accuracy at each epoch that is dependent upon the available design knowledge. Figures of Merit (FOM) stipulated for the IRSTS are listed; and it is noted that for FOM 1 there is a 20% difference between the value predicted at the end of the first epoch and the resulting value; a 10% difference at the mid-point design when theoretical data were supplemented by flight test results. It was not until after the third epoch that reliability test information for the system became available; and these data were combined with total flight test data to provide the final system effectiveness value.
M.W.R.

Review: Part of this paper consists of outlines of the information necessary for performing analyses utilizing the WSEIAC concept for several systems of interest in the Air Force. These outlines will make excellent checkoff material for those implementing analyses of the WSEIAC type. The paper is based on a study made by the Hughes Aircraft Company, and apparently additional and expanded outlines for other systems are given in the Hughes report which is referenced in the paper. The finding reported in the paper to the effect that necessary data for these analyses are generally available but perhaps scattered is an important conclusion because most reports and studies concerned with systems analysis indicate that availability of data is a problem. No mention is made in this paper of any actual applications of the WSEIAC concept. (The WSEIAC reports were covered by R65-12200.)

R68-13773 ASQC 814
SYSTEM COST-EFFECTIVENESS: AN APPLICATION.
B. P. Barnes (ARINC Research Corp., Annapolis, Md.).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructuve Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 38–46.

The ASQ-19, -57, and -88 communication, navigation, and identification (CNI) systems presently used in the F-4 aircraft were found to be inferior to candidate replacement systems according to all selection criteria except initial cost. Basic criteria used in the comparative analyses were inherent capability, effectiveness, mean time between failures, and availability of the equipment; as well as cost, volume, weight, power input, and procurement lead time. For specific equipments such as the UHF radio, TACAN, AIMS-compatible IFF, ADF amplifier, and UHF receiver, it was shown that a completely new system would increase aircraft capability to perform CNI function and provide savings in power, space, and weight. Details are presented of the application of a system cost-effectiveness analysis to decision making; cost effectiveness is described, the problem is isolated, control measures and alternatives are identified. The system modeling is noted, candidate systems are compared with and without interrogation, and a cost effectiveness summary is tabulated.
M.W.R.

Review: This paper describes a case study in which cost effectiveness analysis concepts, previously applied largely to force structures and large systems, are applied to an electronic subsystem. The essence of the approach is to condense the detail so as to make the measures of the cost and the effectiveness for each alternative stand out clearly. Some features of the application as described in this paper raise questions which may bother the close reader. There is a lack of clarity in the descriptions. Effectiveness is defined as the product of availability, dependability, and capability. It is then stated that only dependability will be used as the measure of effectiveness, and further that MTBF will be the measure of dependability. The reason given is that capability is the same for all systems and that no changes in repair time are expected. In the illustrations which follow, there are different performance levels for the various alternatives. These are so acknowledged and are treated individually. Capability is not defined in the paper, and apparently it means something other than different performance levels for the alternative systems. When availability is dropped from the effectiveness measure coupled with the same average cost per maintenance action for each alternative, it would seem that some important inputs are lost. For example, if a failed equipment means a failed aircraft, then certainly this should be reflected somewhere in the cost effectiveness analysis. Sometimes the practice is to carry more units of an equipment which is known to have low reliability. The cost and effectiveness comparison tables in the paper are apparently on a per unit basis with no reflection of the cost for increased units to meet some total availability constraint. Spares, test equipment, and technician training are other considerations. At one place in the paper the commonality point is mentioned, but this does not appear in the actual alternative analyses which are later shown. One crude way of reflecting these considerations would have been to use a different cost per maintenance action for different alternatives. These points are raised in the spirit of searching for how best to apply cost effectiveness notions at the smaller subsystem level. The case study which is described undoubtedly contributed to a better decision than would have been made without it.

R68-13776 ASQC 813
ENGINEERING RELIABILITY INTO TODAY'S AUTOMOTIVE VEHICLES.
J. Knowles (Ford Motor Co., Technical Analysis Office, Dearborn, Mich.).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Intitute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 67–74.

Building reliability, quality, and safety into automobiles is considered in an overview that deals with the factors that complicate such efforts and presents the major facets of an industrial reliability assurance program. Programs at various design and manufacturing levels are noted, controls that have been implemented are presented, and the development of improved diagnostic and service techniques are mentioned. Aspects of the overall operational program are concerned with product planning, vehicle systems, program engineering, and reliability analysis. Requirements include the definition of such reliability requirements, design to achieve reliability, verification testing, specification of component requirements, and monitoring of field information. The control item concept for complying with federal safety regulations is discussed,

manufacturing validation efforts are reviewed, and quality assurance of both components and assembly operations are considered. M.W.R.

Review: The question an aerospace reliability man can ask of this paper is "What can I learn about aerospace reliability from these reported experiences of an automobile manufacturer?" Now this aerospace reliability man has had experience in relating actual situations to the official company line about them. Therefore, what he will learn from this paper is not necessarily what the author intended that he learn nor what the author tried to say. One of the first things to learn is that complexity is the enemy of reliability—that many different models and frequently changed models contribute to unreliability. (Perhaps the reliability engineer should stress to management that a trade-off adverse to safety and reliability is being made by proliferation of models and frequent design changes.) Another point to be learned is that competitive pressures do not necessarily increase the reliability or safety of a product. It is also easy to infer that items which must meet the government's specifications are treated somewhat differently than those which need not, even though the company may strive hard to meet both kinds. Certain items which affect reliability and safety when subject to federal specifications are removed from competitive pressure and thus management cannot make trade-offs concerning them. The discussion of the reliability program per se is good. The reliability group presumably has staff assignments rather than line responsibility and acts in the capacity of consultants. Thus, reliability appears to be the responsibility of the design engineer and he gets help from the specialists and testing laboratories as necessary. During the design reviews the producibility of an item is subject to careful scrutiny; this is a valuable concept which is often omitted in many companies. No mention is made of how reliability requirements interact with the production line itself, with workers whose sense of responsibility often flags, and in situations where shutting down a production line is so costly that it must be kept going almost without regard for any but the most dire consequences. Thus, there are many things that an aerospace engineer can learn about his own reliability problems from this article if he reads it wisely.

R68-13777 ASQC 813
MANUFACTURING ASPECTS OF RELIABILITY CONTROL.
Bernard E. Ricks.
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 75–80.

A manufacturing approach for reliability control includes overall improvement of the manufacturing system by improving gauging techniques, laboratories that engage in nondestructive testing techniques, zero acceptance and zero defects tools, and personal reliability on the part of those concerned with the manufacturing process. An existing system and the controls and responsibilities it imposes is discussed, and the role of the human operator in implementing the reliability program is stressed. M.W.R.

Review: This paper discusses an incentive program to encourage production-line workers to do the job right. In addition to attempting to provide emotional and intellectual incentives, the program attempts to provide the worker with the proper tools to do his job and the proper records to show that he has done it right. It sounds like a good program, but naturally is subject to erosion by time as are many such programs. Those not versed in the vagaries of people and complex manufacturing processes may presume that everything will run smoothly, just the way it is shown on paper. Others will wonder what happens under the pressures of deadlines, budgets, and unions. These are difficult things to discuss in a public paper because they affect the company's image, its profits, and its relationships with customers and unions. The impression is given that manufacturing's only job is to make "it" like the drawing. This seems to eliminate feedback to design which is essential, and also does not consider the fact that no drawing can completely describe a product or process.

R68-13783 ASQC 813; 815
THE RELIABILITY ASSURANCE PROGRAM OF MIL-STD-790B.
Donald L. Kear (Defense Electronics Supply Center, Engineering Standardization Directorate, Dayton, Ohio).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 122–130. 35 refs.

History and background of MIL-STD-790B are explained, along with documentation, responsibilities, and requirements of its prescribed reliability assurance program for electronic parts specifications. Both responsibilities of the manufacturer and the qualifying activity with regard to enforcing program requirements are stated; and the program plan documentation that must be submitted by the manufacturer to the qualifying activity is discussed. The manufacturer must present data on his operational structure, test facilities, failure analysis, and corrective action evaluation test procedures and their implementation. Program documentation required to be retained in-plant, but made available for review by the qualifying activity personnel at the manufacturer's plant, is concerned with training, calibration, proprietary processes and procedures, failure and defect analysis, corrective plan of action, and clean rooms. Other areas that are discussed are production processes; procurement, production, and process control; handling and packaging; conforming and nonconforming materials; traceability of materials and processes throughout production; and the controlled storage areas. M.W.R.

Review: The primary role served by this paper is to draw attention to MIL-STD-790B (Reliability Assurance Program for Electronic Specifications). A good, brief treatment of the background and philosophy of the standard is given on the first page. The relationship of the standard to established reliability (ER) specifications is clearly brought out in that discussion. The remainder of the paper is a narrative, matter-of-fact description of various aspects of the plan. It is useful material to have around as a supplement to the standard, since it provides suggestions on interpretation and implementation. Much of the emphasis is on documentation required of the manufacturer. It is noted in the paper that one or two significant changes from earlier originators of this change deserve a "hats off" acknowledgement, at least for their intent.

R68-13785 ASQC 810; 831
RELIABILITY AND MAINTAINABILITY CONSIDERATIONS FOR TOTAL SHIP SYSTEMS.
P. J. Giordano (Sperry Rand Corp., Sperry Systems and Management Div., Syosset, N.Y.), and J. Sacks (Naval Ship Systems Command, Naval Ship Engineering Center, Washington, D.C.).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 155–163. 2 refs.

Shipboard mission requirements are discussed in terms of reliability and maintainability design and analysis and their integrated support requirements. The evolution of a systems approach to and its impact on ship development is discussed; and attention is given to mission responsive goals, integrated logistic support, and the determination and system modeling of effectiveness measures. The Navy's system performance effectiveness program has resulted in handbooks and guidelines such as data retrieval techniques, generalized modeling techniques, prediction techniques, technical communication formats, redundancy techniques, performance standards, and procedural manuals. M.W.R.

Review: Reliability and maintainability in their broadest sense are considered in this paper. An overview of the application of systems effectiveness concepts to shipbuilding is presented, indicating that drastic changes are in order. Contrasts with aerospace-oriented applications are noted. For example, a ship's hull and propulsion system have a much longer life than does an aerospace system and there will be several turnovers of many of the subsystems within a typical ship. Actual implementations of the systems effectiveness concepts noted in the paper are largely still ahead for the shipbuilding industry. The current status is apparently that of initial contract definition studies. A minor nuisance to the reader in this paper is that the figures are not numbered. However, they do seem to be presented in the order to which they are referred in the text, which is a help.

R68-13786 ASQC 814

PROCUREMENT VIEWS OF LIFE CYCLE COSTING.

W. J. Ryan (Headquarters Naval Material Command, Washington, D. C.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control, New York, IEEE, Inc., 1968, p. 164–168.

Maximum potential of a Life Cycle Costing (LCC) concept is considered to be in the initial procurement of major systems when major reliability and maintainability parameters are established. It is recommended that LCC be used as part of an overall selection procedure that includes acquisition price, technical merit, and other factors. Potential savings from using the LCC concept diminish as the material acquisition level descends from major systems through subsystems, although subsystems procurement is still considered a fertile area for LCC application; and the payoff from the application of LCC procurement to nonrepairable items is significant. Application criteria are presented, along with the criteria which govern resulting benefits; and details are included of criteria for systems procurement, systems reprocurement, subsystems procurement, parts procurement, and general item procurement. M.W.R.

Review: The Naval viewpoint on life cycle costing (LCC) as a source selection criterion in a contract award is well expressed in this paper. The presentation is refreshingly devoid of the message so often conveyed by government personnel to the effect that "all our problems are solved" and listing the things which others must do. The author recognizes reliability as a major economic factor. Reliability workers will be pleased to hear a procurement person speak in this vein. LCC will help to allocate reliability and maintainability efforts properly; however, as the author points out, continued assistance will be needed from reliability and related disciplines. The final sentence of the paper is worth emphasizing, namely: "Future expansion of...LCC...is primarily dependent on...the capability to reasonably quantify and demonstrate reliability and maintenance costs."

R68-13787 ASQC 814

AIR FORCE APPROACH TO LIFE CYCLE COSTING.

George S. Peratino (Air Force Dept., Washington, D. C.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control, New York, IEEE, Inc., 1968, p. 184–187.

Air Force study groups have been established to investigate 10 tasks associated with the concept of Life Cycle Costing (LCC) in equipment procurement. These involve reliability prediction, maintainability prediction, maintenance costs, verification and demonstration, and supply management; as well as training, operating cost, service life, equipment selection, and contractual provisions. Some activities of the task groups, either by themselves or in cooperation with other task groups, are mentioned. M.W.R.

Review: The history of life-cycle costing (LCC) in the Air Force is traced in this paper. An Air Force study group concerned with LCC identified ten tasks, the first of which was reliability prediction. This paper is mainly of background interest, although some of the tentative findings on each of the tasks may be of some immediate use to those working directly with LCC. Two reports mentioned in the paper immediately following this one in the Proceedings (p. 188–192) expand on some of the topics mentioned in this paper.

R68-13788 ASQC 814

SURVEY OF LIFE CYCLE COSTING PRACTICES OF NON-DEFENSE INDUSTRY.

Perkins C. Pedrick (Logistics Management Institute, Washington, D. C.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 188–192.

The widespread use of Life Cycle Costing (LCC) in non-defense industry is noted, although its use in industry varies substantially from that used in a government environment. Industry, for example, has placed greater emphasis on the methods of analyzing cost estimates than has the Department of Defense. An overview is presented of a survey of LCC practices of non-defense industries, based on data submitted by nine major industrial companies in the fields of wood products, oil, chemicals, paper, vehicle manufacturing, household consumer products, instruments, and air transportation. Methodology for LCC is discussed, including cost estimating, estimates of useful life, estimates of value, and maintenance and support cost estimates. Attention is given to methods of analysis, establishment of source selection criteria, practices that facilitate LCC, and controls on cost estimates. M.W.R.

Review: The purpose of this survey of life cycle costing (LCC) practices in non-defense industries was to generate ideas for improvement of DoD LCC applications in the procurement process. That which the author labels LCC is more often called cost-benefit (C-B) analysis in non-defense applications. The term "cost-effectiveness" (C-E) is common for defense applications, with the essential difference between typical C-B and C-E being that C-B measures cost and value in monetary terms whereas C-E may include non-monetary costs, more typically called constraints (e.g., volume or weight) and effectiveness is not measured in monetary terms. Some of the survey findings apply also to such non-defense sectors of the government as those concerned with water resources. The paper does not use the terms C-B and C-E, and they are cited here in order to help readers in relating the jargon of different sectors. This paper will provide background information for reliability

workers interested in cost analysis. It calls attention to the vastness of the U.S. government-industry complex, explicitly pointing out that what are new discoveries in some sectors are "old-hat" in others. Those seeking references should look for the terms C-B and C-E as well as for LCC; no references are given in this paper. Some key factors related to the differences between current DoD practices and those used in non-defense industries are cited in the paper. Others would seem to be that DoD operations must be open to scrutiny whereas non-defense industry is not, that the DoD sector has a C-E problem whereas non-defense industry has a C-B problem, and that the government-defense industry is very often dealing with systems which are at the frontiers of the state-of-the-art, while the non-defense industry is applying well-established technology (some of which has been picked up from government-defense technological developments).

R68-13790 ASQC 813; 770; 844

THE TEG—A TEST ELEMENT FOR THE CONTROL OF QUALITY AND RELIABILITY OF INTEGRATED CIRCUITS.

Erwin A. Herr, Donald W. Baker, and Albert Fox (General Electric Co., Semiconductor Products Dept., Electronics Park, Syracuse, N.Y.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society of Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 201–216.

A program statistically designed to encompass the entire production cycle of integrated circuits led to the generation of instructions for a procurement specification that uses a Test Element Group (TEG) to monitor the quality and reliability of integrated circuits fabricated with diode isolation. It was shown that TEG was a key monitoring instrument during fabrication, and that TEG carries the process history through to the final test. Pellet and assembly processes can be quantitatively related to critical TEG parameters which predict circuit characteristics and influence stress performance. The assembled TEG can be used in stress testing of elements and their interactions for early accelerated simulation of potential circuit failure mechanisms. The TEG technique was found useful in analyzing the chemical and physical mechanisms of failure; and decreasing failure-in-time models developed for both linear and logic circuits support a burn-in effectiveness hypothesis. The use of TEG in process control is shown graphically, and several step-stress flow charts are included. M.W.R.

Review: This is an enthusiastic paper written with a positive attitude. The principle of making sample devices on the chips appears to be worthwhile and the benefits are ably documented. This method of checking reliability and quality is certainly much nearer to fruition than the general approach described in some of the other papers in the Proceedings. There will undoubtedly be practical difficulties associated with the use of this technique and it will surely face competition from other methods as time goes by. Two of its main advantages are: (1) it is well within the state-of-the-art and (2) it lends itself to contractual specification.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13747 ASQC 824; 511; 851

RELIABILITY TESTING—APPLICATION TO RCA TIME DIVISION DATA LINK TESTING PROGRAM.

W. J. O'Leary (Radio Corp. of America, Defense Electronic Products, Missile and Surface Radar Div., Moorestown, N. J.).

In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 1–2 to 1–8. 8 refs.

Sequential sampling plans for reliability testing are discussed in general; and the resultant design graphs are used directly to show their application in an industrial data link testing program. Test design equations are evolved; and slope of the decision line, intercept of decision lines, operating characteristic curves, average test time, and truncation policy are discussed. Details are included for the use of the sequential reliability test design graphs. M.W.R.

Review: While one would not guess it from the title, this is largely a paper on sequential testing. Appropriate dimensionless parameters are introduced in terms of MTBF and discrimination ratio. Curves are given for the easy design of some of these tests. All the calculations are made for non-truncated tests, although consideration is given to truncation. No reference is made to the more recent work of Aroian (see, for example, R64-11401, R65-11854, and R66-12753), who has shown how these sequential tests can be truncated without affecting the originally-assigned risks. This is done by utilizing the slope in the approximations of the original calculations. Those who must design tests may find these curves of value. It should be noted, however, that a sequential test (which is essentially an accept–reject situation) cannot be substituted directly for a test that required the estimation of a parameter. For example, the term confidence will be used differently in the two cases.

R68-13750 ASQC 823

TO BURN-IN OR NOT TO BURN-IN.

John La Capra (Radiation, Inc.).

In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 6–2 to 6–11. 5 refs.

Underlying distribution theory and mathematical techniques are presented for assessing the amount of reliability improvement that can be expected after burn-in for a specified period under simulated end-use conditions; and results are included for some log normal and Weibull life density functions. Included are the reliability function after a burn-in; the ratio of this result to the reliability function without burn-in; and the portion of the original population that is expected to survive burn-in. The decision to use burn-in to improve component reliability should be based on the behavior of the underlying hazard function and the assessment of the cost model representing the pertinent tradeoffs for the program in question. A burn-in program, however, may be expensive because there is generally a large loss of parts; and loss of over 50% of the parts is considered likely. Some numerical examples are included. M.W.R.

Review: This paper is extracted from the report covered by R65-12211.

R68-13758 ASQC 824

TABLES FOR OBTAINING THE BEST LINEAR INVARIANT ESTIMATES OF PARAMETERS OF THE WEIBULL DISTRIBUTION.

Nancy R. Mann (North American Rockwell Corp., Rocketdyne Div., Canoga Park, Calif.).

Technometrics, vol. 9, Nov. 1967, p. 629–645. 16 refs.

A censored life-test situation is considered and the assumption of a Weibull distribution for failure times is made. Tables are given for estimating log reliable life, where the estimator is best among linear estimators with expected loss invariant under translations. These best linear invariant (BLI) estimators have uniformly smaller expected loss than the Gauss–Markov best linear unbiased (BLU) estimators and are simple linear functions of the BLU estimators. The preliminary discussion involves a comparison of the BLI estimators with other widely used estimators. Author

Review: In addition to the tables mentioned in the title, this paper contains a good concise discussion of the properties of these estimators. A comparison of linear and maximum likelihood estimation is given. There are also some comments regarding the accuracy of the tables. The discussion is keyed to sixteen references, so that the relationship of the present work to previous publications is adequately indicated. The paper is primarily mathematical rather than applications-oriented. It makes a worthwhile contribution to the theory of reliability estimation.

R68-13759 ASQC 824

PROPERTIES OF A METHOD OF ESTIMATING RELIABILITY IN AUTOMATIC CONTROL SYSTEMS.

M. B. Slavin and L. Ya. Tsikerman

(*Avtomatika and Remote Control*, vol. 26, Dec. 1965, p. 2281–2285.) *Automation and Remote Control*, vol. 26, May 1966, p. 2203–2207. 14 refs. Translation.
(A66-34676)

A discussion is presented of a method for assessing the reliability of automatic control systems, which takes into account the properties of the controlled plant. The error probability in control is taken as the reliability criterion. The magnitude of the error depends on the parameters of the time distribution to the occurrence of both a hidden failure and an inadmissible deviation of the control parameter in an automatic control system. Expressions are derived for determining the error probability in control for an exponential and a normal time distribution to system failure, and also for a Weibull distribution. IAA

Review: This paper appears to provide little that is new. The author is concerned about degradation of system parameters (called invisible or hidden faults), but does not consider the degree of degradation. Therefore, in his analysis it has made no difference whether he was concerned with degradation or catastrophic failures. The time interval he considers is the time from appearance of the degradation to its detection during scheduled maintenance; the times to the occurrence of such faults may have Normal, exponential, or Weibull distributions. The author attempts to distinguish between the possibility of an error in the control system and the occurrence of degradation, but one can discern how they are related only by working backwards from one of his formulas. Apparently, after the degradation has occurred, the probability that there will be an error in the control system is given by the exponential formula with a particular parameter. The physical basis for his analysis is not at all clear. Thus the paper will be of little use to anyone.

R68-13760 ASQC 821

RELIABILITY INVESTIGATIONS OF ELECTRIC DISTRIBUTION NETWORKS.

Zoltan Reguly (Polytechnical University, Department of Electric Power Plants, Budapest, Hungary).

Periodica Polytechnica—Electrical Engineering, vol. 10, 1966, p. 99–123. 11 refs.

Mathematical concepts and operations used for investigating reliability of electric distribution networks are presented. Using set theory and probability arithmetic, it is shown that a general method can be evolved for the numerical evaluation of the reliability of widely varying network configurations as well as for determining the maintenance outage rates. Included in the mathematical survey are the derivation of applied basic concepts of set theory and fundamental concepts of probability theory. Reliability rate and unavailability rate can be used to determine network dependability; and series, parallel, combined series and parallel, and mesh connected elements are considered along with a system provided with a redundant element. Selection of probability variables, maintenance outages, and maintenance of series and parallel elements are considered. M.W.R.

Review: While the title of this paper refers to electrical distribution networks, the paper is in essence an introduction to set theory and probability theory as needed in reliability calculations. As such it is good. It is apparently designed for people who know little if anything about these two theories and develops the ideas in a reasonable fashion. This kind of introduction is probably more readily available elsewhere to people in this country, but this one suits the purpose admirably. Many engineers who misuse the theory would do well to review something like this.

R68-13769 ASQC 823

A STATISTICAL INTERPRETATION OF RELIABILITY.

Charles Lipson (University of Michigan, Department of Mechanical Engineering, Ann Arbor, Mich.).

Metal Progress, vol. 93, Feb. 1968, p. 70–72.

The use of statistical methods, particularly probability curves, for determining reliability is discussed; and some hypothetical and real-data curves for probability prediction are presented. The fallacy in designing for average life is stressed, although it is noted that reinforcing design with empirical safety factors permits designers to live with the average life concept. Data plotted for ball bearings tested at 475,000 psi are used to show how reliability curves can be put to practical use. M.W.R.

Review: This short paper can be useful if its main impact is to introduce engineers to the probability-of-survival curves, but the details can be misleading. Some of the disadvantages are the following. (1) No references are given for more detailed, more exact treatment. (2) "Average, by its definition, corresponds to 50% reliability." The ordinary average is the arithmetic mean which does not so correspond. The average the author must have in mind at this point is the median. (3) The fraction of satisfactory parts included between various points on the Normal distribution curve is listed to four significant figures. Inasmuch as a further statement uses a term "...closely approximate a Normal distribution curve," it would have been advisable to reduce the number of significant figures so that an unduly close approximation is not implied. (4) "These curves, which represent events that occur by chance alone, ..." This statement is at best ambiguous. It is interesting to note that many authors have used "by chance alone" to imply the Poisson distribution, not the Normal distribution. A random variable, i.e., one whose value is determined by chance, has a probability density function and any variable which has such a probability density function is in fact a random variable. (5) The term "50% failure rate" is used to describe the case where one designs to the average life. This is an unusual meaning for the term "failure rate." It would have been better to omit the word "rate." (6) In describing Fig. 5, the statement is made that "...the design life of

engine valves must only be average life." Apparently it should read "...must only be *30% of* average life." (7) Fig. 3 is called a skewed distribution curve and cumulative percent is given as the ordinate. They would be correct if it were in fact a cumulative distribution curve. But it is a density function, so that it is mislabeled and also has an incorrect vertical scale. The vertical scale should be in terms of probability of occurrence and such that the area under the curve is unity. Figures 4, 5, and 6 were apparently derived from a log-Normal distribution. The curves are obviously not generic for the items indicated, but apply to a particular design or type of design. The term "life" is somewhat ambiguous in these contexts since it is not always clear whether it refers to the life of a particular item, median life, average life, mission time, or possibly something else.

R68-13775 ASQC 823

ESTABLISHMENT OF RELIABILITY STANDARDS THROUGH TESTING.

Charles Lipson (University of Michigan, Department of Mechanical Engineering, Ann Arbor, Mich.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 62–66.

The relationship between failure and reliability in automotive parts is considered, and the variation in service life of automotive parts subjected to identical loading is noted. Therefore, the testing of number of samples to obtain an average or mean reliability has become widespread in the automotive industry. The drawback in using the average alone is mentioned, as is the need for generous safety factors in design calculations based on such mean values. Statistical methods are required to permit meaningful analyses of the variation or dispersion in component reliability, and a study is described in which the normal distribution was employed to provide useable results. Average life versus design life is illustrated, and design life factors at the 95% reliability level are charted for flexual and contact leading conditions. Design life factors for various components are tabulated at the 90, 95, 99, and 99.8% levels. M.W.R.

Review: This paper is essentially the same as the author's paper in Metal Progress, vol. 93, Feb 68, p. 70–72 and the difficulties mentioned in the review of that paper in this issue of RATR apply virtually verbatim to this paper. Two examples of these difficulties are the following. (1) A beginner would certainly think that the author was using a Normal distribution; whereas, the logNormal distribution is the one applicable to the parts he is discussing. (2) In the case of the logNormal distribution, the median and mean are not the same; yet the author states that they are. This paper is suitable only for the most rudimentary introduction to reliability, whether automotive, aerospace, or anything else. The data the author gives are obviously much more restricted than the description of the components might appear. Since the author knows better and the Symposium Program Committee knows better, it is difficult to see how this paper was published.

R68-13743 ASQC 838

Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.

REDUNDANCY OPTIMIZATION FOR SPACE COMPUTERS

Narsingh Deo *In its* Supporting Res. and Advanced Develop. 28 Feb. 1967 p 59–61 refs

(N67-23645)

Redundancy optimization for space computers is discussed, including even and partial redundancy methods. Theorems are presented for the probability of system failure, reduction of failure by increasing redundancy, and increasing probability of failure by adding an extra module. M.W.R.

Review: This paper is too condensed to be of much use to anyone but a theorist and in that case the omission of the proofs and of any mention of where they may be found is a disadvantage. An important omission is the explicit statement that failures of all subsystems are presumed statistically independent. In the case of an even number of subsystems the criteria for failure are not given (in particular the case of the 50–50 split is not explicitly treated). Virtually all the comments on this paper result from its extreme brevity. The author refers to an earlier paper on the same subject (see R67-13241).

R68-13745 ASQC 838

Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

COMPARISON OF DIGITAL AND ANALOG MECHANIZATIONS OF A TRIPLE-REDUNDANT, SELF-ADAPTIVE FLIGHT CONTROL SYSTEM

Kenneth Elmer Schultz (M.S. Thesis) Jun. 1966 105 p refs

(GGC/EE/66-17; AD-639697; N67-16203) CFSTI: HC $3.00/MF $0.65

As a result of research performed for the Air Force, two laboratory models of a single-axis, triple-redundant; self-adaptive flight control system were constructed. Both models demonstrate extensive use of integrated circuits; but one system employs analog circuitry, while the other is essentially a digital-differential-analyzer. An objective system comparison is achieved with an exponentially weighted figure of merit incorporating numerical measures of system effectiveness with respect to seven comparison criteria: Complexity, cost, performance, power, reliability, volume, and weight. The unique trisafe analog redundancy method is the primary reason for the overall superiority of the analog system. Author (TAB)

Review: This paper illustrates in a practical way how decisions can be made about one type of equipment versus another. The author takes extreme care to show the uncertainties and arbitrariness that are involved in any such decision, even down to what factors are to be included in the arriving at the decision. The many devotees of Maintainability as a discipline will be disappointed to see that item left out (and asserted to be included under cost). The author abandons a linear sum figure of merit in favor of a product type, but it should be noted that since each one of the factors in the product is considered to be of the form exp(-kx) or exp(-k/x), the product form has turned back into the sum. It is also then readily apparent that the author's weighting factors are now combined with the k's, and thus the author's choice of k significantly affects the ultimate weighting. The author is to be commended for his frank discussion of the uncertainties and arbitrariness involved in the decision-making and for pointing out that preciseness in the arithmetic should not be equated to correctness of decision. Many people who have in the past suggested comparing figures of merit for various processes seem to have neglected these all-important facts. The paper is written in an informal style which is easy to read and it can be of value to those who are interested in learning how to apply some simple decision theory to their problems. It

does not pretend to be the last word, but the many cautions inserted by the author are not found in the usual articles, for example, in trade magazines.

R68-13753 ASQC 830; 813

RELIABILITY PREDICTION IN DESIGN OF MICROELECTRONIC AEROSPACE SYSTEMS.

Robert W. Cherney (North American Aviation, Inc., Autonetics Div., Data Systems Div., Anaheim, Calif.).

In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 23-2 to 23-26.

(A66-42098)

Demonstration that much existing data are usable in the microelectronic reliability prediction and design application problem by interference from applicable failure mechanism knowledge gained in discrete component test and evaluation history are presented. Factors of overstress probability for fail-safe design criteria are considered. Mathematical prediction models and actual systems achievements correlating with reliability predictions representing a practical method have implemented this approach and are shown for such equipments as the Minuteman guidance computer. Systems considered involve integrated circuits, thin film circuits, and metal-oxide-semiconductor field-effect transistors (MOS FETs). IAA

Review: This paper is difficult to follow because of the poor editorial preparation (it appears to end three times, a large block of pages is out of order, and the proof-reading was generally poor). The discussion will be most meaningful to people who have gone through similar programs. The paper does make many good points—both about the difficulties of achieving a reliable system and about the difficulties of estimating the reliability, especially the future reliability of microelectronic devices. The term "inherent reliability" is used in several places. In some it appears to be more meaningful than others, but the biggest problem with the term is that it provides a large handle for the buck when it is passed to someone else about failure. There is some use of too many significant figures in failure rates. (For example, a ratio between 8 and 20 was presumed to hold for failure rates of inhouse data versus field data and a factor of 10 was selected as being appropriate. Then an additional factor of 1.45 was included. The accuracy of the latter factor is completely swamped by the uncertainty in the original one. Then in one of the graphs, a failure rate goal is stated to be 1.84900%.) Little emphasis is given to screening for achieving high reliability; perhaps it is implicitly included somewhere. In short, the paper probably provided the basis for a good talk, but its value as reference material is slight.

R68-13774 ASQC 831; 615; 817

EFFECTIVENESS EVALUATION USING DYNAMIC PROGRAMMING.

G. E. Neuner and R. N. Miller (TRW Systems, Redondo Beach, Calif.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 47–61. 5 refs.

An analytic method based on dynamic programming principles is presented for evaluating the multi-dimensional relationships among parameters that describe the characteristics of a complex system. Preparatory efforts and problem formulation are described for the method that permits evaluation of alternate design configurations and management policies in order to optimize a system that can achieve maximum effectiveness. Solution techniques using the search method, Lagrange multipliers, and dynamic programming are discussed; and the last is detailed along with the dynamic programming algorithm employed. Key outputs, computer programming requirements, and a numerical example illustrate the use of the dynamic programming method; and application of its use in the design of an interplanetary spacecraft is presented. For this illustration, the generation of input data, computer output and summary graphs, and producer and customer interpretation of results are presented. M.W.R.

Review: This is a well-written paper on the subject of optimization and trade-off of the parameters which encompass operational capabilities of a complex system. The authors discuss the use of search methods and the method of LaGrange multipliers; however, the preferred technique for optimization in this application is dynamic programming (DP). The use of a computer is necessary for systems of any reasonable complexity. No program or flow sheet of a computer program is given; however, such a program can usually be written in a few man-weeks of programming effort. It would be of interest to know a little more about the effort involved in writing the TRW computer program discussed and if it is proprietary. Assuming that the problem of dimensionality (and the resulting storage in the computer) does not prohibit the use of DP, then it is a valuable tool in evaluating the effectiveness of complex systems. It is to be noted that the optimization procedure selects the optimal subsystem configuration from among a prior finite set of configurations; it does not select the best configuration by addition (one-at-a-time) of standby, active, and spares as described in many papers on optimization. This paper can be of help to design engineers and program managers having responsibility for optimization and trade-off decisions with regard to complex systems. A private communication from the first author indicates that the estimate of a few man-weeks of programming effort is fairly accurate. Furthermore, the problem of dimensionality (and the resulting storage in the IBM 7094 computer) does not become serious until the number of system parameters employed becomes greater than five. The latest generation of large computers should give even greater capability. It is also stated that the DP technique permits evaluation of all types of reliability improvement such as changes in operating procedures, alternate assembly methods, etc., as well as alternate levels of redundancy.

R68-13779 ASQC 830; 770

SEMICONDUCTOR DEVICES FOR THE SF SUBMARINE CABLE.

A. J. Wahl (Bell Telephone Laboratories, Reading, Pa.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 86–90.

Product design and development, fabrication, screening, aging, and selection of semiconductor devices for the SF submarine cable are considered in terms of increased reliability required of such components. In-place testing during long-term aging has completely eliminated the problem of device mix-up and damage due to handling during aging; and over four million individual tests were performed without damage to devices. No aging trends of other than transistor or diode parameters were detected; and during a period of over two and a half years more than 75 million device hours of power aging under worst case use conditions resulted in

no failures or in any trends of practical significance. Aging was accomplished by soldering devices into the aging modules in groups of 100 per module. M.W.R.

Review: This paper shows the extremes to which it appears to be necessary to go in order to insure the reliability of a device as simple as a transistor or diode. (The monitoring system described here, while not explicitly referenced, is apparently the one described in the paper covered by R68-13583.) The design philosophy, which is essentially to stick to proven products and processes only, to be extra careful, and to pay even more attention to detail is in contrast to situations where the management trade-off is not always in favor of high reliability—such as in military equipment (by this or any other manufacturer) or automobiles.

R68-13784 ASQC 831

EFFECTIVENESS OF SHIP SYSTEMS AND MACHINERY.

Igor Bazovsky and Glen E. Benz (Genge Industries, Inc., Scientific and Consulting Div., Sherman Oaks, Calif.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control, New York, IEEE, Inc., 1968, p. 131–136. 39 refs.

Relationship between the effectiveness of a ship system and its subsystems and shipboard machinery is discussed; and an example of machinery effectiveness modeling techniques is presented. The selection of effectiveness measures for some ship subsystems and machinery are discussed as they relate to functions which must be provided to insure successful ship missions. Mathematical models are evolved, and a numerical example is included that determines the probability of the effectiveness of a pump in a cooling system aboard a ship. M.W.R.

Review: This is an introductory paper. A large portion of it is given over to explaining the meaning of effectiveness in language that managers, for example, can understand. It would be just as applicable to any other kind of a system as to ships. The discussion is reasonable and can help the neophyte. The numerical example is the same one found so often where failure is defined essentially in terms of a generalized stress and strength. Unfortunately the authors do not solve the example—they indicate in the first paragraph of the example that the pump output is dropping because of wear, presumably in a deterministic way. The problem they solve is one in which the pump has a mean output and a probability distribution on either side. This fact may cause some confusion to the careful reader since the two situations are quite different and are solved in different ways. The correct solution is related to the zero-crossing problem and is solvable by numerical methods. (The correct answer is 8.3% insufficiency rather than 6.9% as calculated by the authors.) Perhaps the confusion arose because the equation for pump output as a function of time looks similar to some stochastic equations.

84 METHODS OF RELIABILITY ANALYSIS

R68-13742 ASQC 844; 711; 712

National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.

SOME FAILURE PROBLEMS IN SPACECRAFT AND SPACE BOOSTERS

A. J. Babecki, J. D. Grimsley, and H. E. Frankel Jul. 1966 42 p Presented at William Hunt Eisenman Failure Analysis Conf. of the Am. Soc. for Metals, New York, 12–14 Jul. 1966

(NASA-TM-X-55607; X-735-66-406; N67-13223) CFSTI: HC $3.00/MF $0.65

Several examples are given to show the common failures of metallic components which occurred during simulated service testing. Some are attributable to excessive stressing which occurs as a result of unrealistically high vibrational specification requirements; others to exhaustion of fatigue design life of the part because it was subjected to an excessive number of repeated mechanical tests. Improper processing and inspection during fabrication, materials selection, and design are identified as other causes. Also considered are the failures which occurred in unmanned scientific satellites during testing of prototype or engineering models. The factors causing corrosion, fatigue, extreme brittleness, and anisotropy are assessed in relation to the use of specific materials. Booster failures are attributed to defects in steel, processing, and fabrication. M.G.J.

Review: This NASA report is similar to the paper by the same authors covered by R67-13169. The emphasis is on failure analysis, e.g., the causes of mechanical failures, fatigue, and poor choice of materials or processes in design. The notorious inadequacy of data in handbooks and on data sheets for the materials is also scored. The case histories are worthwhile reading for designers because they show the ease with which mistakes can be made. Materials or processes which have served well in the past may become culprits due to an added environmental factor. Names such as "high strength" are misleading because they refer to only one of the properties in the material; many of the other properties may be degraded, e.g., brittleness, sensitivity to hydrogen embrittlement, susceptibility to stress corrosion, ductility, and fatigue. Probably what is needed are more check lists for designers who use mechanical parts, so that it is easier for them to consider all of the details. An appreciable effort should also be made to store much of this knowledge in computers, so that the analysis can be quickly, easily, and completely done (which is usually not the case when the designer must handle each situation by itself in a tedious way). However, the report suggests that designers should make greater use of materials specialists in the design stages as well as during failure analyses.

R68-13744 ASQC 844; 433; 872

Navy Electronics Lab., San Diego, Calif.

A BAYESIAN MODEL FOR TROUBLESHOOTING ELECTRONIC EQUIPMENT Research Report, Jan.–Jul. 1966

R. L. Hershman and M. Freitag 9 Nov. 1966 22 p refs

(NEL-1412; AD-645577; N67-23939) CFSTI: HC $3.00/MF $0.65

Bayes Theorem is applied to the problem of formulating an optimum strategy for the troubleshooting of equipment failures. The probabilities attaching to hypotheses about the various possible causes of system failure are modified according to the theorem, and the process of testing and replacing components is structured so as to minimize the expected total cost of system restoration. Author (TAB)

Review: This paper suggests an approach to the repair of electronic equipment which minimizes a figure of merit, taken in the paper to be cost. No mention is made of the fact that there

may be a restraint in addition to the figure of merit, e.g., minimum cost within the constraint of a given time; but presumably the method could be adapted. A big difficulty concerns the immensity of the task of getting all of the prior information that is required. It may be that in any practical situation the problem becomes more like a game of checkers or chess. There the strategy does not attempt to look at all possible combinations, because of the enormity of the task. The idea presented in this paper is worthwhile and should spur further efforts toward solving the problems of optimum maintenance procedures. Contrary to some implications that these calculations will be less necessary with automated test equipment, they may even be more necessary for the actual programming of that kind of equipment.

R68-13746 ASQC 844
REDUCING FAILURE RATE PREDICTION UNCERTAINTIES.
D. A. Hausrath and D. C. Fleming (North American Rockwell Corp., Autonetics Div., Anaheim, Calif.).
In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 226–235. 25 refs.

Different published failure rates for a given electronic part type are used to reduce the uncertainty of predicting the reliability of electronic parts. The prediction method accounts for various factors that affect part failure rates and describes the dependency of failure rates on both design maturity and equipment age, with the latter maturation effect considered particularly significant in predicting equipment reliability during total life cycle. Integrated circuit data used in the Minuteman 2 electronic equipment provide the basis for the prediction model; and failure rates and mode data formed a pattern which partly suggests the reasons for different failure rates published by different agencies. Factors affecting electronic part failure rates are tabulated, as are failure modes with respect to time and operational failure rates supplied by various suppliers for temperatures between 25 and 125°C. M.W.R.

Review: The authors have done a reasonable job of trying to clear a path through the jungle of failure rate numbers. It is not the only path that could be cleared and it may not even be the best one, but it is a path that has a considerable amount of rationale behind it. The problem and its solution are virtually all in the area of engineering judgment but that is why it is a jungle. Many people will be queasy about using supplier-furnished data, but it *is* information and should be better than none—when properly interpreted. In the discussion of maturation, several probability distributions are bandied about in a cavalier manner; however, none of it is central to the argument of the paper. It is interesting to compare this paper with the one by Troxel and Tiger appearing on pp. 217–225 in the same Proceedings. There is not necessarily a conflict of interpretation, but it certainly would not be hard to think there was. The reader is still left with the problem, after reading the many articles on failure rates for integrated circuits, of what he should do. The best advice is to take an approach that both you and others have found reasonable. Then see if the results, in terms of your own decisions, are extremely critical to the exact technique employed. If the exact technique makes a big difference in your decision, then you have problems that will not go away easily. If the exact technique does not affect the decision, then you can be confident that your decisions are not unreasonable.

R68-13751 ASQC 844
FAILURE EFFECTS IN Si–SiO_2 INTERFACES.
A. Goetzberger (Bell Telephone Laboratories, Inc., Murray Hill, N. J.).
In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials, and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 13–1 to 13–5. 8 refs.

Ion migration and surface state failure effects associated with silicon–silicon dioxide interfaces are outlined. Ion migration causes changes of the surface charge and device failure results by channeling; and means of avoiding ion drift effect discussed are: (1) total exclusion of sodium from device processing and encapsulation, (2) use of phosphorus getters, and (3) use of insulators not based on silicon dioxide. It is noted that interface states can be created or annihilated by annealing in dry or wet ambients and that increased surface state density results in reduced gain of transistors. The change of surface state density, however, happens at higher temperatures than does ion migration; and is, therefore, less critical. M.W.R.

Review: This tutorial paper is both brief and clear, so that even today—almost two years after its publication—it serves as an admirable introduction to a fast-growing technical area. The author has pared all non-essential details from his discussion to present an easily-followed but accurate review of the electrical properties of the Si–SiO_2 interface. The crispness of his account can probably be appreciated most by the newcomer; into two pages of text, the author has compressed the significant results of hundreds of publications. Such a brief treatment in a conference proceedings of limited circulation will not be of major impact but nevertheless the job is well done. The paper does have editorial defects of varying consequences: (1) misspellings—both those that are obvious and therefore unimportant as well as those that are less obvious and perhaps confusing ("silica" for silicon; "from" for form), (2) figure captions have been lost in the reproduction—consequently specific values of oxide thickness and doping levels in Fig. 2 are not given; the labels A and B in Fig. 3 are not defined, (3) figure order is interchanged—what is labelled Fig. 2 is referred to in the text as Fig. 1 and vice-versa; Fig. 3 is placed before Fig. 2, (4) the title above the text differs from that above the author's biography.

R68-13752 ASQC 844; 775
ROLE OF NOISE IN FAILURE MECHANISMS IN TRANSISTORS.
Alan P. Stansbury (Quan-Tech Laboratories, Inc., Whippany, N. J.).
In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 14-2 to 14-6. 5 refs.

Use of noise as a detector of failure mechanisms in transistors is discussed, and its proper application is stressed. Fractures, contaminates, erratic breakdown, and high current densities are cited as the major defects that noise measurements can detect. It is concluded that noise testing techniques will continue to be a very powerful screening tool in the thin film and integrated circuit development. M.W.R.

Review: This paper makes an interesting contrast with a review paper by Goetzberger (Paper Number 13 in the same proceedings). The Goetzberger paper embodies most of the desirable properties of a review paper; this one illustrates the opposite. Nothing is defined. The reader is assumed to be familiar with the terms: thermal noise, shot noise, 1/f noise; he is also presumed to be familiar with methods of measuring noise. The author talks about elements of an equivalent circuit for noise measurements

("noise current generator"), but the equivalent circuit is not illustrated or described. The abscissae of Figs. 1, 3, and 4 are not explained, nor is the factor of 10^9 difference in scales between the abscissae of Figs. 3 and 4 commented upon, even though the devices and the measurements being made seem similar. The reader is assumed to be familiar with the meaning of Rg. The paper consists of 12 paragraphs plus a conclusion. The first four paragraphs are irrelevant to the subject being discussed; the paper could begin at paragraph five with no loss of content. Five references are cited but all of the citations are incomplete so that the reader cannot locate any of them without further information. In three cases only titles are given—no authors, no journals or any other information about them. The reader may glean useful bits of information from the paper; for example, transistors with narrow base widths (and hence high current gains) operate at lower base currents than a wider base transistor, assuming a fixed value of collector current; the lower base current results in a lower noise current for these units even though such narrow base transistors are often more susceptible to failure than the noisier units with wider bases. The overall impression, however, is that the paper merits little attention and that the reader should learn about noise as a device screening measurement from other sources.

R68-13755 ASQC 846
OPTIMUM USE OF MICROELECTRONIC RELIABILITY DATA IN SYSTEM DEVELOPMENT.
John R. Lennon (ARINC Research Corp., Annapolis, Md.).
In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 25-2 to 25-11.
(A66-42099)

This paper summarizes the latest microelectronic data and suggests methods of applying the findings during system development. The data analyzed are discussed in relation to the sources from which they were obtained. These sources include integrated circuit manufacturers' device tests, system manufacturers' device tests, system manufacturers' and users' equipment tests, and operational systems experience. Data from each source, if properly understood, can provide considerable insight into source selection, packaging, testing, specification, interconnection technique, and other system development problems. Of particular interest are the reliability data resulting from over 250 million hours of integrated circuit operation in prototype systems. Author (IAA)

Review: This paper merely describes (1) various kinds of life tests that can be run, (2) some of the properties of the data obtained therefrom, and (3) kinds of data that can be obtained from system operation both in the plant and in the field. Some of the problems to look out for when a device is actually used in a system are listed—most have to do with interface and handling problems. No mention is made of the influence of screening on the reliability of devices and, as other papers in the conference have pointed out, screening is extremely important where high reliability is necessary. There is a table which gives device hours and numbers of failures for over 15 systems. It is useful in showing the scatter in the data. The points that are made are good, but the kinds of information in the paper do not live up to what many would expect from the title.

R68-13761 ASQC 844; 775
SEMICONDUCTOR RADIOGRAPHY: ITS STRENGTHS, WEAKNESSES AND THE CONTROLS NECESSARY TO ASSURE ITS EFFICACY.
M. Michael Roth (Continental Device Corp., Hawthorne, Calif.).
Materials Evaluation, vol. 26, Jan. 1968, p. 8–12

Strengths and weaknesses are presented for semiconductor radiography, which is used to verify nondestructively that the devices have been assembled in compliance with required quality standards. Such a verification is predicted on the proposition that units which exhibit some types of physical abnormalities have an inherently higher failure rate than normal high quality units, and that the more likely to fail units should be called out of "hi-rel" lots. Capability of X-rays to penetrate opaque objects is the main reason for its use as a nondestructive testing tool for semiconductors. In addition, X-rays can provide a permanent record, there is ease in measurement, and results can be viewed on screens. However, it is noted that X-ray equipment is costly, there are variations in X-ray cross sections of the various materials in semiconductors, and there is difficulty in correlating X-ray results with mechanical inspection. Controls employed to assure the quality of X-rays are presented, along with some of the techniques for overcoming X-ray semiconductor radiographic weaknesses. Photographic examples are presented. M.W.R.

Review: This disquisition, as the author labels his paper, makes some obvious (and some perhaps less obvious) comments on the use of radiography as a tool for screening semiconductor devices. Its technical content can be summarized briefly: (1) X-rays are useful for screening devices because they enable one to observe and to record structure without delidding; (2) the X-ray absorption cross section of the materials found in packages varies; (3) the resolution of each exposure should be monitored by including a calibrated test region; (4) during evaluation, fluorescent light does not heat the film as much as incandescent light; (5) practice and/or a fluoroscopic presentation are of help in interpreting the X-ray data. Perhaps the paper's most important contribution is the evidence presented that failure to appreciate these seemingly-obvious facts in the past has led to misinterpretation of X-ray data which in turn has been expensive for both vendors and vendees. The paper is written for the non-specialist and constitutes a brief digest of one manufacturer's experience with X-ray radiography. (The author in a private communication has indicated that his company will supply copies of the paper upon request.)

R68-13762 ASQC 844; 846
ASSESSING SURVEYOR SPACECRAFT RELIABILITY FROM TEST DATA.
Thomas M. Drnas (Hughes Aircraft Co., Space Systems Div., El Segundo, Calif.).
Quality Progress, vol. 1, Jan. 1968, p. 13–17.

Practices and procedures used to assess Surveyor spacecraft reliability are discussed, including a mathematical model that permitted reliability assessment on the basis of data from spacecraft mission simulation and actual mission flights. The model consisted of reliability block diagrams to visually express the spacecraft equipment configuration as well as probabilistic expressions that represent the reliability of units mathematically derived from applicable probability density functions. In deriving the model it was assumed that no human errors would result in failure, equipment and inspection test procedures would be perfect, only standard operating procedures would be considered, and meteorites and deep lunar dust would be nonexistent. Spacecraft reliability data flow is shown; and subsystem and unit reliability estimates are tabulated. Problem areas considered are the updating of the model, concepts, and data processing procedures; the generation of inaccurate and untimely data; and the means of providing management with effective data. M.W.R.

Review: This is a brief article which is suitable for giving engineers and management a rough idea of how the reliability

analysis and documentation on completed vehicles proceeds. At this level of presentation it is difficult to give any detailed criticism or plaudits because the supporting information is not available. Apparently some kind of average hazard rate is calculated for each interval of test (by dividing the appropriate failure number by the appropriate operating time), which is reasonable. The principles in use appear quite straightforward and of the variety that have been advocated for some years. The author does make an effort to bring practical everyday problems to the reader's attention, especially with regard to the collection and assessment of data. Much of his advice in this regard directly reflects the principle that if someone does not work for you, you have little control over how well he does his job and consequently you may not be able to depend on the results he gives you ("If you want it done right, do it yourself"). There are no references to further information; undoubtedly the author can supply them.

R68-13765 ASQC 844; 711; 714

CORROSION CAUSES AND CURES.

Machine Design, Nov. 9, 1967, 4 p. 4 refs.

Material selection, surface treatment, and protective coatings were considered at a conference dealing with metal corrosion problems and their control. Basic corrosion is reviewed, along with electron exchange, detection, and polarization. Rust density, protecting alloys, and effect of pH were reviewed in connection with the corrosion of ferrous alloys. Mention is made of corrosion problems associated with nonferrous metals, including aluminum alloys and magnesium, titanium, and copper and their alloys. Both design considerations and stress corrosion are discussed for nonferrous materials. Various sacrificial primers with barrier topcoats that provide outstanding resistance to specific environments are noted. High-build epoxy, epoxy-polyanide, vinyl, acrylic, and silicone coating uses are briefly described. M.W.R.

Review: This is a summary of four papers from a conference on corrosion problems and controls (sponsored in part by NASA). The abstracts are somewhat technical for the trade magazine in which they appeared and for the intended readership. They will probably be more effective as scare stories than in terms of education. However, if mechanical and design engineers read this paper they can be made to realize that corrosion is a very complex problem, that it can be very insidious, and that they should have assistance from someone who specializes in this area. Corrosion in one form or another is certainly a mechanism for performance degradation in both the electronic and mechanical areas. It leads to catastrophic failure in unexpected ways.

R68-13767 ASQC 844; 711; 713; 714

WHY TITAN'S BOLTS FAILED.

Louis Raymond (Aerospace Corp., Metallurgy Research Section, El Segundo, Calif.) and Ernest G. Kendall (Aerospace Corp., Metallurgy and Ceramics Dept., El Segundo, Calif.).

Metal Progress, vol. 93, Jan. 1968, p. 103, 104, 107, 108.

(A68-18000)

Discussion of the causes of bolt failure on the thrust-control valves of a Titan vehicle. It was found that the bolts, which were constructed from the martensitic, age-hardening alloy 17-4 Ph, failed due to hydrogen embrittlement. Several methods for the prevention of this phenomenon in the 17-4 Ph alloy are discussed. IAA

Review: This is a physics-of-failure type of paper and shows the extremes to which analysis of detail must sometimes go just to analyze the failure. A legitimate question naturally arises to whether as much detail and analysis as this would have been worthwhile beforehand on every possible part. This paper is an example of the reasons why design engineers should have the advice of experts in corrosion (whether metallurgists or chemists) to assist them in their design. This is especially true when properties are being pushed to their limits; e.g., high strength steels generally have tendencies toward poor performance in other characteristics and it may be difficult to find the optimum combination of properties.

R68-13768 ASQC 844; 711; 714

Pacific Naval Lab., Esquimalt (British Columbia).

RELIABILITY AND CORROSION

R. D. Barer Repr. from Naval Eng. J., Apr. 1966, p 321–331 refs

(R-66-2; AD-639567; N68-83565)

Achievement of reliability is considered in terms of attention to choice of materials and design of ship structures and machinery, and some examples are included to illustrate means of increasing reliability and the role of corrosion hazards in materials selection. Use of aluminum casting alloy and aluminum piping materials is discussed, and an example of a copper–nickel–iron material for finned tubes exposed to salt water flow is considered. For the last, it was found that a spiral turbulator which increased turbulence and removed more heat from the air outside the tubes also increased contact or crevice corrosion. Removal of these turbulators arrested corrosion and permitted repair of damage. Drying drum failure caused by lack of attention to reliability; weaknesses in stainless steels, aluminums, and brasses; bilge protection against corrosion and corrosion fatigue failure in boiler tubes of a ship's power plant are also treated. For the latter two, measures are noted that can insure reliability even after some damage has been caused by corrosion. M.W.R.

Review: This is a good paper. It is short and readable, and the examples are chosen with care. Corrosion and stress corrosion are important stress mechanisms in aircraft and missiles as well as sea-going vessels. One of the author's most important points is that designers must know the properties of their materials under the actual conditions of use—the properties given in handbooks are often misleading. Corollaries to this principle are (1) the actual conditions of use are not always the specified conditions and (2) environmental specifications created by people behind desks may be inadequate. In one of the author's examples, the specified metal took the sea water environment adequately—it was the seagull droppings that did it in.

R68-13780 ASQC 844; 770; 813

RELIABILITY TECHNOLOGY IN ACCELERATED TESTING.

Daniel P. Guzski and Alfred Fox (General Electric Co., Semiconductor Products Dept., Electronics Park, Syracuse, N. Y.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 91–102. 4 refs.

A physics of failure program was designed for testing a high reliability silicon double heatsink diode (DHD) which incorporates a passivated epitaxial planar (PEP) pellet. The junction is diffused into a high resistivity N-epitaxial layer grown on a low resistivity silicon substrate. Pellet selection, screening, burn-in, accelerated stress, and correlation units are discussed, and the failure prediction model for the DHD was of the deterministic degradation variety that used the relationship of the failure mechanisms, the kinetic

rates, and the probable time of failure occurrence. Effects of high temperature forward bias and reverse bias are considered, and the equations for determining both are presented. The program is presented as an example of how accelerated testing can be used in physics of failure studies to improve product reliability. Further, the program can determine failure mechanisms which can be identified so that the potential failures can be removed by initial characteristics and stress screening; and mathematical failure rate models that are useful to component and design engineers can be generated. M.W.R.

Review: This paper is a rather detailed physics-of-failure exposition on a particular silicon diode. The program appears to have been well planned, well executed, and well analyzed. The paper will be of value to design engineers only in its qualitative aspects. However, it provides reliability engineers with a good case history of what it takes to do a good job and with an example of how accelerated testing can be used without the result's being extremely sensitive to shaky assumptions.

R68-13781 ASQC 844

FURTHER STUDIES INTO CONNECTOR FIELD FAILURE DATA AS RELATED TO THE COMMERCIAL AVIATION INDUSTRY.

James E. Atkinson (Amphenol Corp., Amphenol Connector Div., Chicago, Ill.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 103–113.

Failures of electrical connectors used on jet transport aircraft are considered in terms of environmental and mechanical experiences that cause the failure as well as the actual failure modes and rates. Data presented encompass some 525,000 in-flight hours accumulated by 209 aircraft, or a total operating time of 1,125,913,667 hours for all the connectors involved. Breakdown of each failure category and failure rates are tabulated; and the latter includes adjusted-uncensored failure rates as well as failures not attributable to the device under study and presented as adjusted-censored data. Details are included for connector failure censorship. M.W.R.

Review: Manufacturers and users of connectors will be interested in this paper. From a large amount of data reported by operators of commercial jet aircraft, failure rates are computed for six categories of connectors. Three of these are MIL-SPEC types, viz., MIL-C-5015, MIL-C-26500, and MIL-C-26482. The other three consist of a co-axial types, rack and panel types, and special types. Separate failure rates are also computed for each of several failure modes determined for each type. In part selection or reliability prediction based on these failure rates, consideration should be given to the way in which the failure rates were computed and the assumptions which were made. These are adequately described in the paper. Additional observations and thoughts worth highlighting are: (1) The failure rates are based on in-flight time only. This is no fault of the study but was necessary because of the failure reporting procedures. (2) No distinction is made between static failure rates and mating failure rates as is done in MIL-HDBK-217A. The computation of mating failure rate requires knowledge of the number of matings per unit of time. Some connectors probably have none; however, some may experience many mating operations, say, in routine maintenance operations. The additional effort to determine these and separate the failure rate accordingly is probably not justified. (3) Failure rates represent those for the aggregate of all environments in the aircraft. Even though the data presented indicate that failure rates for each environment could have been obtained, there may be many practical reasons why this was not done. For example, in the tabulated descriptions of the eleven environments the major differences appear only as contamination sources. It is possible, however, that separate estimates would be useful in obtaining a more realistic indication of the dependence of failure rate on environment. (4) Estimates of precision are not included. Since in-flight times will differ among the 209 aircraft, such estimates could require extensive analyses which, if very expensive, could offset any benefits of obtaining them. (5) An overall failure rate for all six categories of connectors was estimated. The only use made of this in the paper is for comparison with some results obtained several years earlier. No comment is made about the statistical significance of the differences; however, with the large volume of data used in the study one would expect intuitively that the differences are statistically significant. In addition, one should generally be cautious of combining failure data on different component types because in the averaging process there can be a loss of identification of components having either very good or very bad failure rate characteristics. Appropriate statistical tests could be used to compare the failure rates of the six connectors and determine whether or not an average rate was justified. The different organizations involved in the failure reporting and analysis of data are to be commended for making these data publicly available.

R68-13782 ASQC 841; 844

NONELECTRONIC RELIABILITY PART DATA COLLECTION AND ANALYSIS.

D. Fulton (Rome Air Development Center, Griffiss AFB, N.Y.), J. N. Holtz, and R. E. Schafer (Hughes Aircraft, Culver City, Calif.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 114–121.

Failure rate data collected on nonelectronic parts are analyzed; and some statistics are included to indicate the types of data available from the literature, data banks, government sources, and industry. While it is noted that reliability methodology for nonelectronic parts has not been developed to the stage of that for electronic components, it is stressed that a fairly large amount of field performance data has been accumulated. The exponential failure times commonly used for electronic part reliability, however, cannot be successfully used for nonelectronic parts; and prediction models for time invariant hazard rates must be investigated and verified. Time transformation, regression, response surface, interference theory, and rate degradation models are currently under study. M.W.R.

Review: The bulk of this paper concerns the techniques used to collect data for the project and will be of concern largely to those who are interested in similar acquisition schemes, or who wish to find any possible bias in this one. The data actually provided are samples and give little more than is available elsewhere. The primary function of this paper, then, is merely to acquaint the readers with one of the extensive projects of the sponsor. (In reporting the distributions presumed to hold for various components, a mixed Weibull is suggested in several cases. As a method of extrapolation, one could as well use the mixed exponential, mixed Normal, logNormal, etc.)

R68-13789 ASQC 844; 824

RELIABILITY PHYSICS FOR MICROELECTRONICS.

T. J. Nowak (North American Rockwell Corp., Autonetics Div., Data Systems, Anaheim, Calif.).

In: Proceedings of the 1968 Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by Institute of Electrical and Electronic Engineers, Institute of Environmental Sciences, Society for Nondestructive Testing, and American Society for Quality Control. New York, IEEE, Inc., 1968, p. 193–200. 16 refs.

Because of the rapid evolution of microelectronic technology and the emphasis on materials, it is contended that reliability technology has not kept apace. State-of-the-art of reliability physics for microelectronics is reviewed; and a number of suggestions are made to bring reliability concepts up to date, including that reliability engineers must become materials oriented because almost all of the available reliability data is on the materials level. The failure mechanism approach to reliability is considered to provide a unified rationale among reliability parameters, device parameters, material property parameters, and the change process kinetics. Kinetic studies of changes in materials that occur during device use should be increased by implementing physics of acceptability programs; and it is recommended that greater use be made of step-stress testing, sensors, pin-to-pin measurements, and devices that survived difficult missions. M.W.R.

Review: The worth of this paper depends inversely on the amount of skepticism one has about the ability of physicists and other scientists to deal with the complicated engineering systems that semiconductor devices are. The approach in this paper is reminiscent of the one tried by RADC at ITTRI several years ago and which showed that the problem was enormously more complicated and difficult than it appeared to be at first. A skeptic, at this point, would repeat Aesop's fable about putting a bell on the cat (it has reappeared in parable form concerning those who make policy decisions and leave it up to others to execute satisfactorily that policy). The practical difficulties in the way of the procedures suggested in this paper (of knowing everything there is to know about every physical process involved in device construction and being able to characterize the material in every necessary way) are extremely great. While some progress is being made, we do not have the vaguest idea of what many of these parameters are or what equations to use to characterize them. A paper by Stewart (see R67-13215) is referenced in the paper and used at least in part as a model. The review of that paper should be consulted for additional remarks which are applicable to this one also.

85 DEMONSTRATION/MEASUREMENT

R68-13754 ASQC 851; 770; 844

BURN-IN AND SCREENING FOR INTEGRATED CIRCUITS.

A. Brown (Cutler-Hammer, Inc., Airborne Instruments Laboratory, Deer Park, N.Y.).

In: 1966 IEEE Conference Record, Annual New York Conference on Electronic Reliability, 7th, May 20, 1966. Conference sponsored by Institute of Electrical and Electronic Engineers, Metropolitan New York Chapters of the Professional Technical Groups on Reliability, Parts, Materials and Packaging; and the Basic Science Group. New York, IEEE, Inc., 1966, p. 24-2 to 24-4.

To determine device integrity and long-term storage capability, ascertain individual device environmental inadequacy, and check lot long-term operating capability, burn-in and screening testing of integrated circuits is being carried out. Lot formation and serialization procedure of an airborne instruments laboratory are outlined; and the drop-out rate in screening and burn-in processing is found to be 2.3% for 10,000 lots that were tested. M.W.R.

Review: This two-page paper is little more than a summary. It does have value in that it contains some details of the tests and some numbers for failure rates. It is too condensed for someone not familiar with the subject, but for anyone who is involved with trying to write specifications or who wishes to know roughly what someone else's experience has been, the paper can be of value. It is doubtful that the author's recommendation (that industry improve its control so that extensive testing is not needed in order to get reliable devices) will be implemented.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 5

Typical Subject Index Listing

PROBABILITY
Procedures for applying sequential probability ratio tests in analyzing checkout and support equipment
TR-3 c84 R68-12733

SUBJECT TERM | REPORT NUMBER | NOTATION OF CONTENT | CATEGORY NUMBER | *RATR* ACCESSION NUMBER

The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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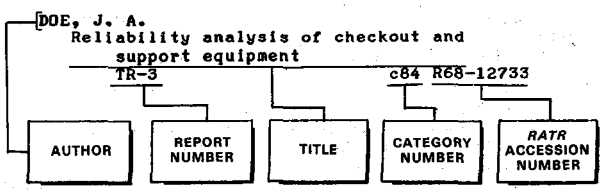
PERSONAL AUTHOR INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 5

Typical Personal Author Index Listing



The category number and the *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

REPORT AND CODE INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 5

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB, STAR,* and *IAA,* respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 5

List of *RATR* Accession Numbers

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Reliability Abstracts and Technical Reviews

JUNE 1968

Volume 8
Number 6

R68-13791—R68-13861

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Use of funds for printing this publication approved by the Director of the Bureau of the Budget October 30, 1964.

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Left-hand labels: *RATR* ACCESSION NUMBER · TITLE · AUTHOR · CONTRACT OR GRANT · REPORT NUMBER

Right-hand labels: ASQC CODES · CORPORATE SOURCE · PUBLICATION DATE · *TAB* AND *STAR* ACCESSION NUMBERS · SALES AGENCY AND PRICE

R68-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65

Left-hand labels: *RATR* ACCESSION NUMBER · TITLE · JOURNAL REFERENCE

Right-hand labels: ASQC CODE · AUTHOR AND AFFILIATION · *IAA* ACCESSION NUMBER

R68-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A68-12569)

Left-hand labels: *RATR* ACCESSION NUMBER · TITLE · CONFERENCE OR SYMPOSIUM REFERENCE · *IAA* ACCESSION NUMBER

Right-hand labels: ASQC CODES · AUTHORS AND AFFILIATIONS · AVAILABILITY AND PRICE

R68-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A68-12407)

VOLUME 8 NUMBER 6

Reliability Abstracts and Technical Reviews

A Monthly Publication

of the National Aeronautics and Space Administration

June 1968

80 RELIABILITY

R68-13813 ASQC 800

RELIABILITY AND HOW IT GREW.

Vernon L. Grose (Tustin Institute of Technology, Santa Barbara, Calif.).

Evaluation Engineering, vol. 7, Jan.–Feb. 1968, p. 46, 48.

An historical approach to the growth of industrial reliability programs is presented, and the importance of management planning by large-scale production facilities is noted. The fact that reliability programs grew because of the complexity and unreliability of equipment following World War II is noted, as are so-called reliability growing pains. Mention is made of the role of the statistician, the generation of government specifications, and the impetus of incentive contracting and space-related research programs in fostering concerned reliability programs. M.W.R.

Review: This is a very qualitative two-page summary of the growth of the reliability discipline beginning with the indefinite past and continuing to the present. Outside of an overly-rosy view of the quality in the past when production was in the hands of "craftsmen," the paper is as reasonable as two pages allow and as a slightly cynical flavor on the part of the writer can produce. It has value as entertainment and as perspective on the growth of such disciplines, but very little for reference. (The text was summarized from a longer paper written for the AIAA System Effectiveness Committee.)

R68-13839 ASQC 800; 810

RELIABILITY AND SYSTEMS EFFECTIVENESS PROGRESS IN CANADA.

Chester I. Soucy (Department of National Defence, Materiel Command, Ottawa, Ontario, Canada) and Hans Reiche (Department of National Defence, Canadian Forces Headquarters, Ottawa, Ontario, Canada).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 236–250. 40 refs.

Military and industrial programs in Canada concerned with reliability and systems effectiveness are described, and actual examples are included to indicate the extent of such programs. It is noted that only 27% of the industrial firms have separate control groups and specialists working on such activities, although many other establishments have specialists working in their engineering, quality control, or other departments. Military program development through the 1950's and 1960's is traced; and various government agencies that implement systems development, acquisition, and support are noted. Canadian specifications as well as contributions related to systems and equipment, electronic equipment, and general technology are noted. Mention is made of the lack of training facilities and personnel. M.W.R.

Review: Canadian progress in reliability and systems effectiveness technology and management are reviewed in this paper. At first glance, the paper appears to be overly long for a subject which is of general interest rather than of technical consequence to American readers. However, on closer examination the reader will find that it is a carefully prepared treatment of the subject, keyed to the 40 references which are cited. There is evidence throughout that the authors have assimilated the essentials of the messages in those papers. Topics covered include the Canadian situation relative to its larger neighbor, military program development in Canada, Canadian specifications, and Canadian contributions in ideas and in systems, equipment, and components. A report on questionnaires sent to Canadian industries is included. The authors make an interesting point about the rapidly-developing fields of reliability and systems effectiveness: Canadians have tended both to examine the sudden accumulation of often-conflicting ideas with a critical attitude and to pay greater heed to some of the doubts and cautions which have been ignored in the reliability gospel-building. Practitioners in this country could well take a more critical attitude. Those concerned with reliability management will find this paper worthwhile reading, not only for the perspective which it presents, but also for some of the ideas which are scattered throughout.

R68-13841 ASQC 800

RELIABILITY ENGINEERING IN FRANCE.

Jacques Eldin (Centre National d'Etudes des Télécommunications, Paris, France).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 254–256.

Status of the reliability engineering and progress related to electronic equipment production in France is described. The common set of French specifications for electronic equipment is mentioned, and efforts at the reliability center at the National Electronic Laboratory are mentioned. Attention is also given to contractual reliability, high reliability involved in development of submarine telephone links and communications satellites, and general developments in reliability engineering in France. M.W.R.

Review: This paper is a brief overview of the state of reliability engineering in France. In accordance with this purpose, the paper contains little if any technical information which would be of value to the reliability engineer. Most of the discussion is concerned with electronic components. While reliability as a discipline has apparently been of concern in France since World War 2, it has not received the attention that it has in this country. In an aside, the author notes that many engineers and management personnel prefer not to be bothered with the exacting discipline of reliability; this, of course, is a frequently encountered attitude in the United States. The difference in degree of space and military programs in the two countries may be an important factor in the differences in the development of reliability. This paper will be of casual interest to reliability workers in this country, although it does convey some perspective on the state of reliability engineering in France that will be of more benefit to those who are concerned in a management way with what is going on abroad.

R68-13842 ASQC 800
STATUS ON RELIABILITY IN THE NETHERLANDS.
H. van der Weiden (N. V. Philips Gloeilampenfabrieken, Eindhoven, the Netherlands).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 258–264.

Because the domestic market in the Netherlands is relatively small, reliability for various types of supplies and equipment is handled directly between supplier and user. Some examples of reliability efforts are illustrated for the food and drug, medical equipment, transport, household appliance, and electronic equipment manufacturing. For resistors, an example of determining optimum component costs is included; and efforts related to the establishment of national inspection systems are discussed in relation to electronic equipment. Specifications, organization, and procedures for such an organization are considered; and some graphs depict reliability predictions, costs, and failure rates based on analyses of field data obtained in the telecommunication field. M.W.R.

Review: The status of reliability in the Netherlands is discussed through the medium of some examples from the food, aircraft, automobile, and electronics industries. In the Netherlands, industry itself pays for all efforts in the reliability domain. This is in contrast to the situation in this country, where many reliability requirements are established and monitored by the government through contracts on space and/or military programs. The author's examples pertaining to food and drugs imply a different interpretation of the word "reliability" than we give to the technical term in this country, as they deal more with the type of regulatory and surveillance functions performed by the Food and Drug Administration. For example, the reference to failure mechanisms of food will seem strange to those accustomed to thinking in terms of failure mechanisms of hardware items. In the example on medical equipment, the failure due to broken wires is the type of thing with which reliability engineers in this country are concerned. The section on automobile reliability deals with topics which we are inclined to put into the brackets of safety and maintainability (although conceptually these are quite close to reliability). In referring to household appliances, the author mentions the difficulty in getting appropriate information from the field, which is, of course, a common problem in this country. In his section on electronic equipments for use in the entertainment field, the author gives a simple example of optimizing component costs in terms of original cost and cost of servicing. In his closing section, the author makes a plea for national systems of authorized inspection which are acceptable to customers in other countries. This is similar to suggestions which have been made elsewhere for international systems of specifications and standards. The author suggests complete, open bilateral exchange of information between suppliers and users. It appears, then, that it is at most the last section of this paper which will be of technical interest to reliability workers in this country, and then only to those concerned with reliability management.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13796 ASQC 812
JUST WHAT IS THE PROBLEM THAT WE ARE TRYING TO SOLVE?
Donald M. Layton (U.S. Naval Postgraduate School, Monterey, Calif.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 449, 450.

Training standards as well as material standards are considered a must in the areas of reliability, maintainability, human factors, quality, and safety. Both value effectiveness training and certification programs are stressed in relation to the concepts of reliability and maintainability. M.W.R.

Review: Two attractive features of this paper are: (a) its intriguing title, and (b) its brevity. It is a short essay on the importance of value-effective training and certification programs in the fields of reliability and maintainability. No references are cited, nor are any details given as to how these programs can be set up and operated. However, the author does refer to some other papers presented at the same conference in which some of these details can be found. A related paper by the same author was presented at an earlier conference in the same series and was covered by R67-13080. The chief function of the present paper is convincing management of the need for appropriate training programs.

R68-13797 ASQC 813
IT IS JUST THE NUMBERS GAME.
William F. Blue and A. Howard Kent, Jr. (Martin-Marietta Corp., Martin Co. Div., Orlando, Fla.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 451–453.
(SAE Paper-670656)

The need for educational systems as well as industrial organizations to place more emphasis on reliability education is stressed; and some industrial experiences with a reliability training program are offered. Major problems covered during five classroom sessions are outlined for an industrial program aimed at bringing reliability into proper focus in the scheme of system design, development, and growth. The widespread use of this program over several years is mentioned, as is the development of a seven book series, entitled "Reliability for the Engineer," that was developed for such a course and has resulted in improved understanding of reliability in the areas of design, manufacturing, and testing. Current programs, it is pointed out, must include more practical applications of reliability techniques and procedures. M.W.R.

Review: Although it is not immediately evident from its title, this paper is a brief description of one company's reliability training program. The program consisted of five classroom sessions and the outline in the paper gives a reasonably clear picture of the essentials of the content. Built around this is a rather convincing case for more emphasis on reliability education. Referring back momentarily to the title, it is not clear that reliability deserves to be called a "numbers game" any more than do some other activities which use figures of merit based on numerical data. Despite this the paper does convey a good message in a clear and concise fashion.

R68-13798 ASQC 810; 433; 824; 844
RISK ASSESSMENT IN COMPLEX UNATTENDED AEROSPACE SYSTEMS.
Anthony M. Smith (General Electric Co., Missile and Space Div., Valley Forge, Pa.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 478–486. 5 refs.
(SAE Paper-670661; A67-34683)

Description of risk-assessment techniques for the design, fabrication, and testing of complex spacecraft. Component-reliability assessment via standard-design reliability techniques and the use of Bayesian statistics are suggested to be an approach for credible relative measures of equipment risk. A special adaptation of the Monte Carlo technique is recommended as a method for obtaining credible absolute measures of system risk. Reliability-trend indicators are also mentioned as a means of risk appraisal. Several examples illustrating the use to which these techniques have been applied are described. IAA

Review: The benefit of reliability analyses for aiding system management in decision-making has been noted many times. Good explanations of just how it is done are rare, but this paper does a good job of this in simple, narrative form. The analysis techniques in the design stage are conventional; however, there is a good illustration of how the "numbers game," even though it uses questionable, generic-type data, aids in determining the bulk of the source of program risk. The incorporation of Bayesian techniques during the fabrication and testing phase to circumvent small-sample data problems is especially interesting in light of its evolving popularity for this use. The Bayesian approach described draws from a more thorough treatment given in a paper covered by R66-12821. As noted in that review, there are certain precautions that should be considered in applying Bayesian methods and in interpreting the posterior results. There is an interesting comparison in this paper of Bayesian estimation with maximum likelihood estimation for the expected life of an equipment. It reflects how the two results converge as more and more test results are accumulated. But even more interesting in the comparison is how the Bayesian posterior estimate stabilizes sooner, even though the prior estimate differs considerably from the final level of the posterior estimate. In the procedure used, the prior information on failure rate is assumed to be a Gamma distribution with the mean taken as the value from a conventional reliability prediction; the standard deviation is taken as a fraction of this mean, where the fraction represents a "degree of belief" in the prediction. The value of the selected standard deviation influences the rate at which the posterior mean settles to its final level. The example does illustrate that the use of the Bayesian method can be beneficial for aiding in the assessment of program risk. Even though the title of the paper emphasizes unattended systems, the techniques apply in many respects to manned systems. The paper by Eagle and Reh in the same Proceedings (p. 487–497) also discusses the problem of risk assessment by reliability prediction.

R68-13799 ASQC 810; 824
ASSESSING PERFORMANCE READINESS WITH THE SATURN V RELIABILITY ANALYSIS MODEL.
Kenneth H. Eagle and John J. Reh (Boeing Co., Systems Assurance Data Analysis Group, Seattle, Wash.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 487–497. 3 refs.
(SAE Paper-670662; A67-34684)

Description of the reliability-analysis model for the Saturn V launch vehicle. A method of quantitative criticality determination is described. In this method, six stage- and engine-reliability prediction models and their associated failure-effects-analysis reports are combined to obtain a basis for criticality determination. A criticality equation is derived. The uses of the Saturn V reliability-analysis model, which extend considerably beyond the normal uses of prediction models, include determination of the probabilities of mission success, vehicle survival, and crew survival. The model is further used to assess performance readiness and to identify critical areas requiring management attention. IAA

Review: The major contribution of this paper is the description of the application of reliability prediction techniques to a large system in order to provide assessment information to systems management to aid in making program decisions. The presentation is clear and easily understood. Performance readiness as defined in the paper is the complement of performance risk. Other components of program risks, viz., cost and schedule, are recognized but are not treated explicitly in the discussion. The assessment of performance risk (and hence performance readiness) is achieved by comparison of component criticality numbers computed from the component unreliabilities with appropriate weighting (the β factor in the paper) to account for their known effects on major system objectives such as mission success, vehicle survival, and crew survival. Of necessity in treating a large complex system, the component reliability models are the simple, conventional form making use of usual assumptions such as independent failures and exponential distributions of failure times; however, there is considerable emphasis on refinement by including only appropriate failure modes and their relative probabilities of occurrence (the α factor in the paper). A significant point is made in this regard concerning the manner of applying these probabilities. Whereas with most analyses, α is applied directly as a multiplier to the failure rate, the authors point out that the correct method is to apply it as a multiplier to the probability of failure. As a simple illustration,

$\alpha(1-e^{-\theta}) \neq 1-e^{-\alpha\theta}$; however, the error in assuming that the two are equivalent is very small for small values of θ. The significant point is that so often the incorrect application is used without questioning its validity, whereas in some cases it can be important. The paper by Smith in the same Proceedings (p. 478–486) is also on the use of reliability prediction techniques for risk assessment.

R68-13801 ASQC 810; 844

DOES RELIABILITY PREDICTION HELP MAKE THE SYSTEM GO?

B. Tiger (Radio Corp. of America, Defense Electronic Products, Burlington, Mass.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 573–575. 3 refs.

Utility, practicality, and validity of reliability prediction tools are discussed; and the understanding of design, production, usage, and management problems is considered a must before the application of mathematical techniques can be successfully applied to identify the best possible systems at the lowest possible costs. It is noted that the use of reliability prediction has been handicapped by overemphasizing the simplicity of prediction techniques; and emphasis on better communication and greater assistance in decision making during design and production is stressed. M.W.R.

Review: Those who have been heavily involved in reliability predictions will recognize the frustrations being touched on in this paper. It is about the right length for a paper which raises problems which do not have clear solutions other than admonitions to try harder. The comments given below should be taken as responses to the author's request for reaction. In his discussion of utility, the author suggests that more elegant analyses than simply adding failure rates for a series of items should be applied more often. However, in many items for which reliability predictions are made, this adding of failure rates is the appropriate procedure, and for some types of electronic equipment, it may, in fact, be too complex. A simple approach based on the number of active elements or class of equipment, or the judgment of an experienced reliability engineer may be as accurate as anything. There are, of course, many potential applications of reliability prediction where more complex models are appropriate. This could be the case, for example, in a complex system such as a complete manned aircraft, or in a situation where the reliability prediction analysis is to provide detailed and comparative information that is to be used for reliability improvement efforts. Complex probabilistic analyses are not easy to do, particularly for those without significant formal training or experience in this area. This point is noted by the author in his discussion of the question of practicality. In his discussion of validity, the subject of data needs is noted. It is suspected that if much better data were available, and that if more of the practitioners of reliability prediction had a stronger background in probabilistic analyses, then there would not be this need to try harder in order to actually influence the design or usage decisions.

R68-13802 ASQC 810; 813; 844

PITFALLS IN RELIABILITY PREDICTIONS.

George Ashendorf (Radio Corp. of America, New York, N. Y.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 576–581.

(SAE Paper-670674)

Problems that require reliability prediction as the basis or one of the bases for decision making are discussed, with the note that reliability prediction capability varies with each situation. Factors which contribute to inaccuracies in final predictions are identified, and the places at which decisions are made are pointed out. Decision making processes are reviewed in the chronological order in which they appear in the various functional phases of a development program from the program definition, preliminary design and systems planning, detailed design, to the actual reliability demonstration. Tables detail the reliability prediction pitfalls at each of these phases; and practicality and validity of predictions are discussed. M.W.R.

Review: About one-half of this paper is devoted to outlines of specific reliability prediction pitfalls. Many of the pitfalls are, of course, the variables which will affect the ultimate reliability. There is no unique way of using, in a reliability prediction, each point on these checkoff lists. Many of the points will not be analyzed in isolation; thus, much judgment will be required in preparing the reliability prediction. The author raises the point of explicit treatment of uncertainty in reliability prediction. He correctly calls for increased emphasis on this in order to improve the validity of prediction. Notions similar to those which reliability analysts have promoted for drift analysis, that is, the sensitivity or end-limit technique and the several methods for the probabilistic treatment of uncertainty, have pertinence in this connection.

R68-13804 ASQC 813; 844

RELIABILITY PREDICTION ACTIVITIES IN THE APOLLO PROGRAM.

George C. White, Jr. and Catherine D. Hock (NASA, Office of Manned Space Flight, Apollo Reliability and Quality Assurance, Washington, D. C.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 587–593. 5 refs.

(SAE Paper-670676; A67-34697)

Discussion of reliability prediction, modeling, and analysis activities taking place in the Apollo program. Reliability modeling and analysis of a typical manned Apollo mission are discussed through an example, the switch selected in the S-IVB stage of the Saturn V launch vehicle. Benefits and limitations of the analytical approach are given. It is concluded that prediction activities have benefited the Apollo program and have been most useful as consistent tools for designers where complete communication is maintained between engineers performing the analyses and those engaged in designing and testing the hardware. A brief summary of the Apollo program is included. Author (IAA)

Review: This brief sketch of how reliability prediction was applied in the Apollo program makes interesting reading. It is essentially a progress report on what must be the largest reliability prediction exercise which was ever attempted. A conclusion as quoted below will help the morale of those reliability workers who sometimes find themselves questioning the utility of reliability predictions. "The reliability prediction and analysis activities in early design and development stages of the Apollo program have paid many dividends in design decisions, redundancy choices, specification requirements, and test and inspection requirements."

R68-13807 ASQC 816

A VENDOR QUALITY AND RELIABILITY INCENTIVE PROCUREMENT PROGRAM.

T. J. Cartin and R. C. Digilio (Westinghouse Electric Corp., Underseas Div., Baltimore, Md.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 623–627.
(SAE Paper-670680)

A pilot incentive procurement has been developed that offers a bonus to a vendor to deliver products that meet delivery, quality, and reliability requirements. In the pilot program, the vendor was permitted to make or lose up to 7% of his normal profit; and in actual practice vendors who supplied 29 different items earned 70% of the possible incentive bonuses. The major contractor experienced his highest total acceptance rate and was able to accelerate delivery schedule of the end product while the incentive bonus program was in effect. It is concluded that such a program is applicable to the majority of materials procured by electronic equipment manufacturers, including nonelectronic parts. The payoff must be sufficient, however, to motivate vendors to meet specifications and deadlines. To develop an overall incentive bonus program, all of the costs of receiving and rejecting procured material must be evaluated and determined to establish incentive ratios. Only immediate acceptance costs were considered in the pilot program. M.W.R.

Review: The procurement of materials which meet delivery, quality, and reliability requirements poses important practical problems for equipment manufacturers. This paper is a clear and concise description of an incentive procurement program in which money is the motivating force (in preference to some less persuasive factor). As such, it has an important message for those concerned with supplier relations in equipment-manufacturing organizations. The purchasing approach which is described should be applicable to a wide variety of material, and variations in the incentive procedures may be introduced in order to meet different kinds of procurements. An interesting point is made early in the paper where the authors comment on the difficulty of keeping emotionally-based motivation programs energized. They say "the major concern in zero defects programs now is to devise techniques to sustain the interest in quality that was achieved at the program's inception." This is an important point which has been made by others who are honestly skeptical of the effectiveness of motivation programs. However, it is a point which is frequently overlooked by the ardent proponents of Zero Defects programs.

R68-13809 ASQC 813

INTEGRATED RELIABILITY PROGRAM FOR SCOUT RESEARCH VEHICLE.

B. V. Morris and R. C. Welch (LTV Aerospace Corp., Missiles and Space Div., Dallas, Tex.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 642–647. Research sponsored by NASA.
(SAE Paper-670682; A67-34702)

Description of the reliability program for the Scout space research vehicle and the changes made to improve this program. The Scout vehicle is designed to launch medium-size payloads into orbital, reentry, and probe missions. The Scout reliability program history and functions are reviewed. A more rigorous and comprehensive program was developed by the NASA Langley Research Center and the Missiles and Space Division in Texas to meet the intent of the NASA Reliability Publication NPC 250-1. This revised program, working in concert with a "recertification" program, has provided excellent results. The organization of this current program is described in terms of design specifications, review functions, malfunction reporting, failed parts analysis, quality control, standardization, and certification. IAA

Review: A reasonably detailed description is given in this paper of the history and functions of the Scout Reliability Program. It serves as an example of the implementation of the intent of NASA Publication NPC 250-1. There is evidence of attention to all of the relevant details during design, procurement, and manufacturing. The subsequent performance history of the vehicle attests to the effectiveness of the program. This paper will be of value to those concerned with the implementation of similar programs.

R68-13811 ASQC 815

THE IMPACT OF ESTABLISHED RELIABILITY SPECIFICATION MIL-C-39003 ON SOLID TANTALUM CAPACITORS.

Harry W. Holland (Union Carbide Corp., Electronics Div., Components Dept., New York, N. Y.).

Evaluation Engineering, vol. 7, Jan.–Feb. 1968, p. 14, 15, 63.

The established reliability specification MIL-C-39003 for solid tantalum capacitors is discussed in terms of the qualification of manufacturers quality and reliability organizations and the acceptance, qualification, and life testing that the contracting manufacturers must perform. Life testing of sample capacitors is described; and it is shown that qualification is granted to various levels of failure rate and the progressive difficulty in attaining lower failure rates is illustrated by the number of part-hours needed for qualification if only one failure is assumed. Tests made on a lot basis are summarized, and the MIL-C-2665B less stringent requirements are shown for comparison. It is concluded that, on the whole, quality of capacitors is improved with the new specification. The obvious advantage to the user is a system of inspection which establishes a failure rate for each production line. Further, a significant quantity of testing on each lot prior to shipment has been added for reliability level M and below. While there will continue to be specialized cases demanding tailor-made test routines, MIL-C-39003A offers advantages to most users. M.W.R.

Review: An overview of the Established Reliability (ER) Specification on solid tantalum capacitors is given in this paper. Although ER specifications for various electronic parts have been in existence for a while, there has not been a great deal of opportunity really to evaluate the ER concept. Typically the cost of an ER-specified part was significantly higher than that of a similar part with an older MIL specification. Now the latest revision to the ER specification for solid tantalum capacitors supersedes the older military specifications for this part. One result will be to force a thorough evaluation of the merits of this ER specification. Thus this overview paper deals with a unique ER specification which might turn out to be a minor milestone in reliability activity.

R68-13817 ASQC 815; 837

(CONCERNING N. N. SOLOV'EV'S PAPER, "AGING TOLERANCES AND RELIABILITY PARAMETERS FOR COMMUNICATIONS EQUIPMENT COMPONENTS.")

O. G. Lositskiy, Yu. P. Sukhov, and R. B. Ulinich *Telecommunications and Radio Engineering, Part 1, Telecommunications*, vol. 20, 1966, p. 64, 65. 2 refs.

Two letters to the editor comment on a Russian paper dealing with aging tolerances and reliability parameters for components of communications systems. These letters question whether one piece of equipment can suffer both gradual and catastrophic failures and note that in the case of an amplifier, failures can be due to drift or overall breakdown depending upon the equipment, operating conditions, spare parts, and feedback. Emphasis is placed on using the best available means for determining reliability, even if this means has its drawbacks. M.W.R.

Review: These two letters are in response to the article covered by R67-13421. It was suggested in the review that the paper was not worth reading, except to see that the Russians are having the same problems that exist in this country with regard to advertising, accuracy of reliability data, and users versus suppliers. These two letters praise the original article for its mention of the difficulties but say that the author's proposed solutions are not proper. They say that one equipment can be subject to both drift and catastrophic failures, that the physics-of-failure approach both in Russian and abroad is making great strides to help in the calculations of both and that engineers should use whatever means they can find to make the best estimates of reliability that they can. Thus, again the only benefit these two letters will have for a knowledgeable American reader is to show that the kinds and extent of reliability problems that we have are not unique or endemic, but are epidemic.

R68-13821 ASQC 815; 831; 838

REALISTIC RELIABILITY GOALS FOR SPACE GUIDANCE AND CONTROL.

H. Hecht (Aerospace Corp., El Segundo, Calif.).
(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 194–198. 16 refs.
(A66-37177)

Analysis of the reliability requirements for guidance and control systems for space vehicles with a mission time between one month and one year. It is considered that modest functional and reliability requirements, coupled with emphasis on the redundancy of existing systems rather than the development of new systems, and a more sophisticated approach to reliability demonstration are required. IAA

Review: This is a philosophic paper which presents a point of view on several topics which are worth considering. The author makes some valid criticism and offers some good advice against unnecessary innovation and complexity. These of course are meant to be tempered by some other kind of judgment, for if we always stayed with what is known, we would still be riding around in chariots. Perhaps most of the author's points can be included in an idea to which he alludes, but does not explicitly formulate; it may be stated as follows. In any prediction of the future we use a model which has two kinds of incompleteness: (a) some hazards that we do not even consider and (b) some that we consider only imperfectly. It does little good to try to decrease the probability of failure of our model below the probability that either one of the hazards (a or b) will occur. Thus in planning a future course of action, it is important that the engineer estimate these two probabilities of incompleteness. This can help him decide whether to stick with old technology which has a fairly low level of incompleteness or to push on to new technology which will have a fairly high level of incompleteness. The more complex a model is, the more likely it is that there will be incompletenesses of which we are not even aware; thus many kinds of complexity are to be avoided on general principles.

R68-13827 ASQC 814

RELIABILITY IN THE REALM OF COST EFFECTIVENESS.

John Lennon (ARINC Research Corp., Washington, D. C.).
(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE. Inc., 1966, p. 226–230.
(A66-37183)

This paper discusses the application of system and cost effectiveness analysis techniques to the procurement of military operational systems that involve contractor performance of "Concept Formulation" and "Contract Definition." The author quotes recent statements made by Secretary of Defense McNamara and former Assistant Secretary Hitch which point to the widening use of these techniques in military contracts to improve the decision-making processes. The author deals, principally, with the need to establish new standards for the development of reliability input data that will result in more meaningful predictions of system and cost effectiveness. He predicts that the growing involvement of industry will raise the state of the art and bring about the desired improvements. The paper defines the ten characteristics that techniques must have to meet future requirements; it reviews some of the shortcomings connected with the present input data collection methods and suggests the needed approach. Author (IAA)

Review: Attention is called in this paper to the difficulties of using conventional reliability prediction in cost effectiveness analyses. The assumption is made that studies in cost-effectiveness analysis are here to stay. Essentially the same message is being noted by others; for example, a government procurement officer made this point in a paper published in the Proceedings of the 1968 Annual Symposium on Reliability, p. 164–168. The present paper concludes with a list of ten "musts" for reliability prediction to be suitable as input for cost effectiveness studies. Their "musts" are challenging but they are not impossible.

R68-13837 ASQC 811

Douglas Aircraft Co., Inc., Santa Monica, Calif. Missile and Space Systems Div.

EFFECTIVENESS ENGINEERING ORGANIZATION IN THE AEROSPACE INDUSTRY

S. L. Roush and J. L. Maybell Oct. 1966 23 p refs
(Douglas Paper-3768; N67-12958)

Effectiveness engineering is the integrated application of selected engineering disciplines to design and development. These disciplines are applied to basic system and hardware design so as to optimize their collective contributions to the successful accomplishment of the mission of the system. The hardcore of these engineering disciplines includes reliability, maintainability, cost analysis, human factors, system safety, and value engineering, all of a line design support nature. Effectiveness engineering is a critical activity of system effectiveness. However, the increasing number of such disciplines in itself became a problem to those very managers who fostered them. A properly structured organization, coupled with clear concise operating instructions and procedures, is clearly the first step in the solution to the engineering portion of this problem. This paper presents a solution to the first part of this preliminary step; that is, a properly structured organization for effectiveness engineering. Author

Review: The effectiveness engineering organization presented in this paper makes sense, as it involves pulling together related

disciplines into a single organization. Of course this is not a new idea, as for some time there has been a use of similar organizations, for example, product assurance. The unique feature of the organization is the inclusion of a cost analysis activity. This is the most important feature in the management sense, as unless "...ability" activity can be put on a cost-effective basis, then it will continue to be a likely candidate for curtailment when dollars become tight.

R68-13840 ASQC 815

A NEW APPROACH TO RELIABILITY ASSURANCE TESTING IN U.K.

L. W. F. Lukis (Royal Marines, Great Britain).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 251–253.

Development of British standards for the reliability of electronic equipment and components is described; and reference is made to two new sections of a guide to reliability programs and reliability assurance testing. Defense and other standards are discussed, as is reliability assurance testing of electronic equipment. General aims of such testing as well as the necessity for using sampling techniques are considered, including aspects of quantity production, complex series systems, parallel systems, and development testing. M.W.R.

Review: A very brief description is given in this paper of current work in producing British standards for the reliability of electronic equipment and parts. The basic objective, that of enabling decision-making to be based on an optimum compromise between statistical risks and engineering confidence, is certainly sound. However, from the small amount of detail presented, no real evaluation can be made of the approach which is taken. For that purpose, it will be necessary to refer to the actual documents which are mentioned; yet no reference is cited to indicate where these may be obtained. However, the author in a private communication has indicated that further information may be found in his paper "A guide to reliability assurance testing of electronic equipments," *The Quality Engineer*, vol. 32, Jan–Feb 68, p. 1–8. A point which is featured in the discussion is that it is possible to test for a high reliability requirement at a low confidence level. Such reduced confidence levels are appropriate when testing a *serial* system by parts. On the other hand, when testing a redundant system by parts, a higher confidence level with a lower reliability is preferred.

R68-13846 ASQC 813

C-141A RELIABILITY PROGRAM.

J. T. Hinely, Jr. and F. A. Stovall (Lockheed Aircraft Corp., Lockheed-Georgia Co., Marietta, Ga.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 288–297. 5 refs.

(A68-19511)

Highlights of the reliability effort of the Lockheed C-141A StarLifter, the first large aircraft developed under full reliability engineering and management requirements. The C-141A was designed and built under direction of the Aeronautical Systems Division of the Air Force Systems Command. It has been produced in large quantities as the prime strategic airlift vehicle of the Military Airlift Command (MAC). Its primary mission is to provide a rapid, reliable, and efficient means of airlifting troops and supplies over long distances and to deliver them by conventional means or airdropping as required. The aircraft has been required to meet the rigid standards of the FAA for type certification as well as the specified military requirements. IAA

Review: This paper presents an interesting narrative description of a large-system contractor's experience in carrying out a reliability program. Reliability management personnel will have the greatest appreciation for it; it would also assist top management in gaining an appreciation for the rewards of a well-supported reliability effort. The program appears to contain all of the essential elements of a well-planned program. One would seriously doubt that all things went as smoothly as the unsuspecting reader might gather from the description; however, there is no doubt about the payoff of the effort. Included in the paper are some results on the relationship of AGREE-type laboratory test results to flight test and operational reliability. Experience shows flight test MTBF to be roughly twice as high as laboratory MTBF. In contrast with experience in many other programs, there was a marked tendency for operational MTBF to be about five times the laboratory MTBF. This unusual experience reflects the results of upgrading operational hardware to include improvements identified through laboratory failures. Some brief, although inconclusive, comments on costs of demonstration tests included in the paper will be of interest to some readers. A number of generalizations based on the program experience are stated at the end of the paper. Several of these are essentially repeats of conclusions stated many times previously in the literature with much less experience to back them up than is obviously available here.

R68-13848 ASQC 815; 817

FUTURE NEEDS AND TRADEOFFS FOR LONG LIFE SPACECRAFT.

R. W. Slocum, E. I. Roberts, and R. J. Smith (Aerospace Corp., El Segundo, Calif.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 303–314.

(A68-19513)

Three basic areas related to long-life military spacecraft are examined. The background for such spacecraft is described, and representative satellite designs are utilized to demonstrate the economic savings achieveable. As an example of the application of reliability specifications to an actual program, the history and development of these specifications in the Initial Defense Communications Satellite Program (IDCSP) are presented. Reliability and quality assurance aspects of proposed programs are then examined from the standpoint of ensuring that specifications will be met. Specific techniques are not considered for achieving long spacecraft life in the various mission areas. It is concluded that sufficient economic justification exists for the development of spacecraft with approximately long average life, depending upon the mission requirements and nature and number of spacecraft concerned. Author (IAA)

Review: The background for long life military spacecraft is discussed, from the point of view of life specification. The Initial Defense Communications Satellite Program is used as an illustration. Five pages of figures and graphs support the description. The paper is clearly written and presents a good general picture of the technical and also the political problems which are involved. However, it does not deal with specific techniques for achieving long spacecraft life. The final section of the paper is an itemized summary

of the reliability aspects of proposal evaluation and source selection. The latter will be of particular interest to management personnel in organizations which are potential contractors on military space programs.

R68-13849 ASQC 813

TIROS—A CASE HISTORY IN RELIABILITY.

R. Hoedemaker, E. Mowleo and George S. Gordon (Radio Corp. of America, Defense Electronic Products, Astro-Electronics Div., Princeton, N. J.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 315–322.

(A68-19514)

Examination of the factors which led to success in the Tiros program—namely, conservative design, conservative testing, and conservative management. Conservative design minimizes the total number of items which could fail, provides a modest degree of redundancy, and results in the operation of components well below the manufacturer ratings. The testing phase of the program discovers marginal components, eliminates potential failures early, confirms design margins, and results in design and component changes. The result is a satellite in which there is considerable confidence of yielding a long life of trouble-free operation in earth orbit. Of great importance was the management decision to obtain from a single contractor the system design, satellite construction, and assistance in the evaluation of in-orbit performance. IAA

Review: Case histories dealing with the reliability achievements of programs which have proven to be successful serve a very useful purpose for those who are working on the design and development of similar programs. This paper presents such a case history, covering the essential features of the TIROS spacecraft. The discussion is clear and concise, and will be of interest mainly to management personnel concerned with the development of spacecraft for long-life missions. The features to which the success of the TIROS program is credited are a carefully patterned plan of program management coupled with a philosophy of conservative design and extensive testing. These are features to be kept in mind and implemented on future similar programs.

R68-13850 ASQC 817

ESTABLISHMENT OF SPACECRAFT LIFETIME REQUIREMENTS.

Eugene R. Carrubba (Avco Corp., Avco Missiles, Space and Electronics Group, Avco Space Systems Div., Lowell, Mass.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability; Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 323–330.

(A68-19515)

Suggestion of a technique for determining mission lifetime requirements of a spacecraft, for the case where the quantity of experimental data becomes a significant factor. The technique is based on a figure-of-merit approach that takes into consideration the value of the data and the probability that they will be acquired. By nature of the factors involved in this approach, other important spacecraft parameters can also be derived. Reliability goals can be established for the overall spacecraft and its major subsystems; and the fractional expected values, summed over the spacecraft mission lifetime, can be used to determine the average value of complete mission success, or figure of merit. IAA

Review: A technique is presented for establishing a mission lifetime requirement for a spacecraft on the basis of the data to be acquired. The idea is straightforward and the explanation given is adequate. The only mathematics involved is a little manipulation with the formula for the standard error of the mean in order to determine the number of observations required in relation to the desired confidence level. Two things may bother the potential user of the approach. First, there appears to be a considerable degree of subjectivity in obtaining the input information, especially in the estimation of the relative dispersion expected in the data. Second, as the author has pointed out, there is no assurance that the technique is optimal in any sense. Other possible approaches would involve the separate evaluation of the factors which limit the mission lifetime, followed by an attempt to work out a suitable tradeoff between them. As the author has indicated, there are pitfalls in these approaches, some of which are overcome by the suggested technique. Thus, it is worthy of consideration for use early in a program for the purpose of guiding design efforts.

R68-13851 ASQC 817; 814; 873

RELIABILITY AND MAINTAINABILITY—TECHNICAL AND COST RELATIONSHIPS.

Henry A. Eimstad, Jr. (Philco-Ford Corp., WDL Div., Palo Alto, Calif.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 331–337. 6 refs.

(A68-19516)

Outline of some principles and techniques for satisfying combined reliability and maintainability system-development requirements while considering associated costs such as developmental and ownership costs. Primary emphasis is placed on the tradeoffs performed during the definition phase, although the basic methods are also applicable to the conceptual and acquisition phases of system development. Considerations for establishing the decision-making team, allocations of requirements, and cost-effectiveness ratio optimization are presented, and cost and effectiveness factors are discussed. A document formulating optimum system design and support strategy is proposed so as to provide a baseline for design implementation and for the preparation and execution of the various program and support plans. IAA

Review: The primary value of this paper is in reviewing some of the aspects of systems effectiveness analyses in the application of tradeoff techniques to be performed during the definition, concept, and acquisition phases of systems development. The cost effectiveness models considered follow those of the WSEIAC report; however, the tradeoff technique presented is not limited to these models. In this paper the author uses systems effectiveness expressed as the product of availability, dependability (reliability), and capability. In the availability formulation he uses the point availability of a serial system. The dependability is given as the reliability of the system assuming the negative exponential failure model. The approach hinges on one having available a certain list of alternatives for analysis; for example, various possible combinations of design features, redundant configurations, reliability and maintainability features. This list is transformed into alternative failure rates and repair rates. The cost and the effectiveness measures are thus expressed as functions of the failure rate λ and the repair rate μ. Then equal-cost and equal-effectiveness curves can be plotted in the μ–λ plane. The optimum values of

μ and λ can be determined and related to the corresponding alternatives. It is to be noted that this paper does not select the best redundant system by a step-wise process as has been considered in several papers on reliability-cost tradeoff procedures. For those engineers familiar with some of the basic aspects of system effectiveness analyses, this paper will have little new material. It will be of most value to those who are being introduced to cost tradeoff analyses involved in an integrated systems analysis. In a private communication the author states that the primary value of the technique is for optimizing an overall system requirement where the system is comprised of several subsystems, each having rather distinctive design characteristics. The method of equal slopes (based on the method of Lagrange multipliers) permits this optimization.

R68-13853 ASQC 810; 841
IMPROVING MEASUREMENT ACCURACY FOR HIGHER SYSTEMS RELIABILITY.
William A. Wildhack (National Bureau of Standards, Washington, D. C.)
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 365–373 14 refs.

Advancements made in measurement techniques to minimize uncertainties in standards, calibration, and final measurements are discussed in terms of improving overall systems reliability. The national measurement system and the international system of measurement units are considered; and some of the uncertainties in standards, calibration, and measurement are noted. An accuracy chart is presented and resources for improving accuracy are discussed, including the use of computers, standard reference materials and data, and measurement agreement comparison studies.
M.W.R.

Review: Measurement accuracy is part of the "infinite attention to detail" required for reliability and this paper gives overviews of the problem and of the organization of measurement standards in this country. Uncertainty as to the error limits in the many measurements on which reliability predictions are made multiplies the uncertainty of the predictions. Uncertainty in the measurements in final reliability tests similarly limits the confidence in predicted performance. It behooves those responsible for reliability programs, as well as those engaged in measurement and calibration, to be somewhat more skeptical as to the organization and operation of their overall calibration and measurement systems. Reducing the number of calibration echelons may be one quick way of improving end accuracy when essential. More frequent checking of working instruments to ensure recalibration when needed is another avenue for closing some of the credibility gaps in reliability. The paper lists several references which will be of help to those who desire more information on the subject.

R68-13855 ASQC 815; 221; 802
RATIONALE AND USE OF MILITARY SAMPLING HANDBOOKS.
Cyrus A. Martin (U. S. Army Mobility Equipment R&D Center, Ft. Belvoir, Va.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 385–390. 36 refs.

A knowledge of government sampling handbooks is considered necessary for acceptance sampling by quality assurance management; and seven of the main handbooks are discussed in this light. Viewed as a set of guidelines with certain common principles among them, the seven handbooks are MIL STD 105-D, 414, 690-A, 781-B, and 1235; H-108; and TR-7. The common aspects of these reliability and sampling documents are discussed and the mathematical basis for the handbooks is considered briefly.
M.W.R.

Review: A very useful purpose is served by this paper in identifying and describing several useful sampling plans published by the military. Most persons concerned with specifying or selecting sampling plans will benefit from the summary presented. The descriptions are brief but highlight important similarities and differences among the plans. In sampling plan selection, the emphasis should be on selecting the appropriate plan to fit the situation at hand. Much too often a particular plan such as a MIL STD 105-D type is specified merely because it is the only familiar one. In some cases it may be readily adaptable, but at the expense of efficiency. Another plan from, say, MIL STD 1235 may be more appropriate. In some cases an existing standard plan may not be suitable and a new plan will have to be developed. Sampling plans can be developed for practically any test and measurement situation involving accept-reject decisions. When given test approaches and assumed distribution of measurement variables are frequently employed, standard sampling plans such as those cited in this paper are usually developed and made generally available. The reference cited below [1] identifies and describes many other sampling plans. As the author states, failure to be aware of and to use such plans is wasteful. The source of Ref. 27 was omitted but the paper appears in the Proceedings of the Aerospace Reliability and Maintainability Conference, Washington, D. C., May 1963, p. 284–311 (see R65-12269).

Reference: [1] Greenwood, J. A. and Hartley, H. O.: *Guide to Tables in Mathematical Statistics,* Princeton University Press, Princeton, N. J., 1962.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13791 ASQC 824; 531
RELIABILITY MODELS FOR DEPENDENT ELEMENTS USING A METHOD OF CORRELATIONS.
R. L. Patterson (University of Florida, Gainesville).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings, Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 364–368. 1 ref.
(SAE Paper-670645)

Models are generated based on the assumption that the interaction of components generates linear statistical correlations among the conditions of groups of components. These interaction effects may be due to active physical mechanisms or may be present even though the elements of the system are physically independent. Formulas are developed for systems in which the elements are in series; and the case of two physically separated fibers, each subjected to a random load, is considered. It shown that the resulting equation can be approximated when the correlation coefficient is large; and this approximation can be generalized and

related to the hazard rates that define failure of a stage. A reliability model is also obtained for a system composed of interacting stages in parallel. M.W.R.

Review: This a loose paper and it is hard for the reader to follow. The analogies which are drawn to certain real-world problems are not precise. The subtitles are confusing. The first one started off with the word "series," yet it is hard to see how this term really applies to the contents. The next subtitle also includes the word "series." It starts out with the series-type problem, but brings in reliability changes after items fail, implying something other than a series criterion of failure. The comments which follow are an attempt to provide some clarification. The part of the paper which is subtitled "Series Systems in which Elements Cooperate" discusses two stress-strength problems, where the strength is deterministic and the stress is distributed exponentially. In the first one a separate load is placed on each of two fibers. In the second one two loads are summed and are placed on two fibers which are defined to have a combined strength of twice that of one fiber. Reliability equations are shown for each of these two problems. The author interprets the fact that the reliability of the combination will always exceed that of the single fibers considered as a series system as "the result of a type of mutual cooperation between the fibers." It would seem that this result could be interpreted more correctly as a result of the averaging of the loads rather than of any mutual cooperation between the fibers. Next the author shows an expression which he calls the ordinary linear statistical correlation. The probability expressions from the two problems noted above are inserted into this expression. The author then notes that this ratio can approach +2; it is evident that he has inserted the incorrect probabilities into the standard formula for the correlation, which must have absolute value less than or equal to unity. The reason why this ratio does not work is that two separate problems are being incorrectly forced together. The first problem would result in his ordinary linear statistical correlation being zero if there was no correlation between the loads, or it would be between −1 and 1 and other than zero if there was any correlation in the loads. Now the problem of the two fibers taken together is really a separate problem. Here it is to be noted that either both fibers will fail simultaneously or they will both be nonfailed. Thus the ordinary linear statistical correlation would be 1. Just exactly what has been developed and where the development is heading is really not clear at this point. The problems involving the fibers do not appear again in the paper. In the two sections which follow, various reliability equations are shown which include the ordinary linear statistical correlation as a dependent variable. It is stated that one of these equations is developed rigorously in the appendix; however, no appendix was published. (The author subsequently forwarded a copy for RATR use.) The author seems to be taking the typical reliability models for series–parallel situations where time is not explicitly treated, and developing some models for various criteria of failure where the usual assumption of probabilistic independence is not made and dependence appears in the equations as the ordinary linear statistical correlation. If this is the idea, it might be a useful notion involving the separation of a complex equation into a group of less complicated equations. It would not, however, seem to be a theory as remarked in the summary.

R68-13793 ASQC 824; 844

APPLICATION OF MAXIMUM ENTROPY IN ESTIMATING THE RELIABILITY FUNCTIONS FOR CREEP FAILURE MODES OF ENGINEERING MATERIALS AT HIGH TEMPERATURES.

A. B. O. Soboyejo (University of Pennsylvania, Philadelphia).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 382–388. 13 refs.

(SAE Paper-670648; A67-34675)

Attempt to establish a formal procedure for deriving reliability functions for mechanical parts, components, and systems from priority considerations of the physical characteristics of the materials and the anticipated loads and environmental conditions. The maximum entropy principle is applied to obtain the prior probability distribution functions for critical creep-strain and creep-rupture characteristics of engineering materials operating at given high temperatures and with uniaxial stresses. A reliability function is derived which defines the probability of successful operation of the material for specified critical creep-strain and creep-rupture modes of failure. It is pointed out that the prior probability distribution functions can be improved by using Bayes' theorem to obtain a posterior probability distribution function when sufficient data are available. These considerations and procedures are illustrated by their application to the stress analysis of a structural component with given mechanical, physical, environmental, and creep characteristics. IAA

Review: This paper is not clearly written. It is difficult to know exactly what the author is trying to do in places because either he gives insufficient information or his procedures are incorrect: 1) An original difficulty stems from the lack of clarity in presenting the maximum entropy principle, especially in the example. It is important to state the result of the example clearly because the maximum entropy principle, at best, leaves much to be desired as a practical rule of operation. The one-parameter case derived by the author should have as its conclusion the following statement: If x is a random variable and the only thing known about x is its true mean, $\bar{x}$, then the distribution of x corresponding to the principle of maximum entropy is $F(x) = \exp(-x/\bar{x})$. The important consideration here is that the variable which has the exponential distribution is the one whose average value is known! In failure modes such as creep-rupture and fatigue it is common to use the logarithm of time (or number of cycles) to failure, and often it is this logarithm whose average value is known, especially if a straight line is fitted to the data points with time plotted logarithmically. In the author's example it is $\bar{\epsilon}$ which is known; therefore it is ϵ itself which has the exponential distribution. Perhaps the author could get from ϵ's having an exponential distribution to t's having that distribution, but the procedure is not given in the paper. This has been in connection with Eq. 26. 2) As another example of the lack of clarity, it is not clear what the author means by an average. If a group of specimens are presumed to come from the same population and their average is taken, naturally the value of this average will not change from specimen to specimen. If they were not from the same population, then of course there would be little point in averaging them in the first place. 3) In a paper which uses considerable statistical notation it is wise not to use the term bias except in its technical statistical sense. In this text the author is using bias and prejudice synonymously. Prejudice is defined by the maximum entropy principle and is not necessarily equivalent to bias. 4) The author says Eq. 28 is true if there is no significant correlation. As in #3 above, a word with a technical statistical meaning has been used without that meaning. The correct criterion is statistical independence. The general problem being attacked by the author in this paper is a worthwhile one, but this paper would have to be completely rewritten to be more clear and/or more correct before it will be of use to anyone. A somewhat different treatment of this same subject is given in the paper covered by R68-13566.

R68-13815 ASQC 821; 838

Joint Publications Research Service, Washington, D. C.

OPTIMAL CONTROL OF SWITCHING ON RESERVE ELEMENTS

I. B. Gertsbakh *In its* Tech. Cybernetics, no. 5, 1966 3 Jan. 1967 p 106–113 refs

(N67-14350)

A reserved system is investigated, the testing of which may take place only at determinate points in time. The number of elements included in the hot reserve after the next check is selected with the intention of minimizing the probability of system failure during the course of the given operating time. The algorithm is presented for finding the optimal policy for switching on the reserve elements, and some of its properties are investigated.

Author

Review: This is a somewhat difficult paper to follow, but the results are of interest. There are considered to be a fixed number of total equipments which can be used in parallel to improve the system hazard rate. When elements are active, all have the same constant hazard rate; when they are inactive they have zero hazard rate. The system is inspected at equal time intervals and the decision must be made at each interval as to how many to leave inactive and how many to make active. The difficulty arises in that if all are made active in one interval, there will be fewer available to be active in subsequent intervals. The first part of the paper is devoted to proving a set of conditions under which the optimum policy is to make all operating elements active. The second part of the paper considers that failed elements can be repaired and again derives a formula for the optimum number to have active at any given time. Most systems are not concerned with this type of problem but in the few that are, the design engineer will be interested in these results. The paper will also be of value to theoreticians.

R68-13818 ASQC 824

CONFIDENCE LIMITS FOR THE RELIABILITY OF SERIES SYSTEMS.

A. H. El Mawaziny (Iowa State University, Ames) and R. J. Buehler (University of Minnesota, Minneapolis).

Journal of the American Statistical Association, vol. 62, Dec. 1967, p. 1452–1459. 8 refs.

Confidence limits are established for the probability of successful operation of series systems that operate only when each of their dissimilar components operates until a certain time. The failure law is assumed to be exponential, and data are assumed available for each type of component in order to provide a large-sample approximation to the exact confidence limits. Maximum likelihood theory and Bayesian solutions are considered, and these are found to agree with those obtained by the large-sample approximation method. An example of the large-sample approximation method is illustrated by making use of a table of random numbers and calculating failure times from an exponential population. The large sampling approximation is, however, not considered applicable to more general systems; although approximations could be developed by maximum likelihood or other methods. M.W.R.

Review: The first author's Ph.D. thesis (see R67-13027) provided an exact solution for confidence limits on the reliability of a series system of k dissimilar components for any k. This paper provides a large-sample approximation to this exact solution. It is a competent mathematical treatment, and the work is adequately referenced. While the approximation is easier to handle in practice than the exact solution, the need for large samples is a problem in much of reliability analysis. The paper is more for the theorist than for the reliability engineer.

R68-13819 ASQC 824

(A PHYSICAL RELIABILITY THEORY.)

N. M. Sedyakin

Engineering Cybernetics, no. 3, May–Jun. 1966, p. 295–303. 5 refs.

Hazard rate and cumulative hazard function are developed during the formulation of a physical law that governs the reliability of materials and systems, and mathematical models are constructed to give a quantitative description of the processes that influence the reliability of a broad class of systems. A solution is offered for the case of a system that consists of two devices, one functionally necessary and the other a reserve, and details are included for various breakdown situations that could arise for such a system.

M.W.R.

Review: This paper can easily be divided into two parts (the second one has important results). In the first part the author discovers the hazard rate and the cumulative hazard function, and finds that they are useful. In the second part he analyzes an important situation; viz., two items are logically in parallel and their hazard rates depend on whether or not the other is working. (Thus statistical independence is not assumed.) This problem is solved quite generally, albeit the solution is implicit and the equations will be complicated to solve in the general case. This is not a solution which is readily found in American literature and so this paper has considerable value. This solution should be extracted from the paper, put in more convenient and usual notation for this country, and republished in one of the engineering journals. (Unfortunately the philosophy that has gone along with the mathematics is worth very little; the title itself is quite misleading—it refers largely to the discovery of the hazard rate.) From the point of view of the mathematics, given the assumptions, the development of Section 3 is correct. But it is cumbersome and can be simplified greatly by writing the "physical law" (1.5)–(1.6) and by doing mathematics in terms of p(t) rather than r(t). The final result (3.13) still obtains. From the practical point of view, it is probably p rather than λ or r which an experimenter can specify most easily, e.g., as the author has done in defining Section 3 through the basic $\emptyset$'s and f's of (3.4) (after which he introduces and works his way out of the unnecessary difficulty of the a's and b's). In fact, λ and r are relevant only inasmuch as they specify p; in Section 3 this is how the author employs them. The reader should beware of the typesetter's many sins of commission and omission.

R68-13820 ASQC 824; 431; 838; 882

SYSTEMS AVAILABILITY MODELING, CONSIDERING COMPLEX AND IMPERFECT SPARING.

Irwin Nathan (Anathon, Inc., New York, N. Y.).

(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 183–193. 6 refs.

(A66-37176)

The importance of realistic systems availability (readiness) models for useful systems and cost effectiveness analysis and evaluation is discussed. A method is presented which considers (1) different types of imperfect failure detection; (2) various replacement strategies, with imperfect replacements and limited spares; (3) different types of scheduled inspections; and (4) noninstantaneous replacement rates and some types of noninstantaneous failure detection. By a careful consideration of the physics of the system and some redefinition, irreducible and ergodic transition matrices are derived from apparently nonirreducible system state transition matrices. This results in the development of a method that not only includes the nonideal system constraints listed above, but gives additional system analysis capability. In many applications this

modeling procedure may well supplant costly simulation studies and increase the knowledge about how the various system parameters interact. Optimization procedures can also be readily applied to the resulting steady-state availability models. This is followed by the addition of a section of comments which indicate some additional applications and some inherent advantages of the methods presented. Finally, a set of conclusions is presented. Author (IAA)

Review: This paper is largely a theoretical development of certain modeling techniques advocated by the author. The introductory material having to do with a need for a cost-effectiveness analysis is readily understandable and straightforward. But those who are not familiar with the theory of Markov chains will find the paper rough sledding indeed (the author gives references to tutorial material). Not all of the mathematics was checked, but it appears to be competent. This paper will be of value to someone who is in the intermediate stage of using this kind of analysis and wishes to sharpen his perceptions on a reasonably complicated example. Going through the paper for this purpose will be quite time-consuming but probably worthwhile. While the author insists on extreme realism in the models, his do have deviations from such realism. For example, he presumes that a system always leaves a particular repair facility (main operating base) in "perfect operating condition." Not only may this not be so, but the term is not well defined when there is redundancy, especially redundancy at a very low level. The important thing of course is to include those details of realism which will make a significant difference in the answer and to exclude those complications which will not. There are essentially two ways in which one can decide to put something in or leave it out of a model. One is to put it in first, find out whether in fact it does make a difference, and if it does not, to leave it out in subsequent analyses. The other more prevalent method is to make a guess at whether the additional complication in analysis is worth the possible difference the assumption might make. (The latter is apparently what the author has done with regard to the above-mentioned deviation from realism and, presumably, with reasonable success.)

R68-13823 ASQC 824; 431; 831

AUTOMATED MISSION ANALYSIS BY MARKOV CHAIN TECHNIQUES.

Charles C. Eliot and William H. Sellers (Raytheon Co., Bedford, Mass.).

(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 204–209.
(A66-37179)

A method of estimating the probabilities of availability and dependability, and of showing the effect of maintainability and reliability on cost effectiveness is developed through the use of Markov chain techniques. Any system may be subjected to one or many mission profiles in its life cycle. The mission profile consists of a number of events where an event is defined as a state which describes the operational status and environmental stresses imposed on the system. Inputs required for this model include failure rates, operational status modifiers, environmental stress modifiers, mean time to repair, and mission events. Outputs of this model are (1) the probabilities of successfully surviving each sequential mission event, (2) the system availability at any time during the mission, (3) the system dependability, and (4) the logistics required for the system for any time period during the mission profile. An example of one application of this technique to a missile system includes a typical mission profile for a ship-based surface-to-air missile. The method of formulating the problem and the results of an actual computer solution of the Markov chain model are given. Author (IAA)

Review: This paper is stated to be an application of Markov chains to an effectiveness model and as such to represent a contribution to the theory. Obviously the paper is not suited for someone not familiar with Markov chains. In fact, the paper is so brief, probably due to editorial requirements, that it is difficult and time-consuming to see where everything comes from. In addition there are a few misprints, which do not help any. For those familiar with the use and application of Markov chains and who have enough familiarity with this particular problem to follow the abbreviated text, the paper can be of use and value. (In an alleged computer printout one of the probabilities is 8.87...which is clearly not correct.)

R68-13826 ASQC 824

RELIABILITY-CONFIDENCE LEVELS.

R. T. Anthony (Westinghouse Electric Corp., Atomic, Defense and Space Group, Aerospace Electrical Div., Lima, Ohio).

(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 223–225.
(A66-37182)

Explanation of reliability statistical confidence levels. It is stated that a statistical confidence interval does not indicate the MTBF of a device, but indicates rather the range within which the true MTBF probably lies with a risk equal to 1.0 minus the stated confidence level that the test results observed could have been obtained if the true MTBF were outside the stated range. IAA

Review: This is a poor paper for the following reasons. (1) it never defines precisely what a statistical confidence statement means. (2) It implies that all two-sided confidence bands are symmetrical. (3) It implies that all single-sided confidence intervals are lower ones. (4) It fails to appreciate the exact derivation of the confidence interval for a fixed time of test (exponential case) and where the addition of one to the number of failures comes in. In statistics where confidence intervals are used, confidence is the fraction of time that the statement given will be true granted that the model being used is correct. Confidence intervals can be one-sided and bounded on either the top or the bottom, or they can be two-sided and can be symmetrical or unsymmetrical (albeit the symmetrical ones are the more common). In short, this paper has little to recommend for it and much to recommend against it. The reader would be better off to get the information from one of the good textbooks on probability or reliability.

R68-13832 ASQC 824; 844

CUMULATIVE FATIGUE UNDER VARIABLE-FREQUENCY EXCITATION.

S. F. Masri (California Institute of Technology, Div. of Engineering and Applied Science, Pasadena, Calif.).

Society of Automotive Engineers, Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., Oct. 3–7, 1966. 12 p. 9 refs.
(Contract NAS8-2451)
(SAE Paper-660720; A67-10607) Members, $0.75, nonmembers, $1.00.

Development of an extended theory of cumulative damage in fatigue when the stress amplitude varies from cycle to cycle throughout the life of the structure. Progressive fracture under variable-frequency excitations occurs in practice during the stopping and starting of apparatus and in testing by sweep-frequency techniques. A description is given of the experimental work that has been carried out with the objective of evaluating failure by fatigue of a beam excited by sinusoidal vibration in which the excitation

frequency varies conti uously. A conventional fatigue test was also carried out to obtain he conventional S–N curve. IAA

Review: This paper describes another of the many attempts being made to improve the accuracy of Miner's rule for predicting cumulative fatigue damage under varying stress amplitudes. It is safe to say that the paper fails to arrive at anything conclusive on the subject although the hypothesis tested is an interesting one. The hypothesis presented (Shanley's) basically evaluates cumulative damage in terms of a nominal stress that is equivalent to a given sequence of varied stress amplitudes. The life for this nominal stress can be obtained from conventional fatigue curves and related to Miner s rule by the use of an exponential factor, λ. An equation is also developed for λ based on fatigue data obtained by variable frequency excitation of cantilever-type specimens. Miner's equation is valid only when $\lambda = 1$. The development of theory and equations will be difficult to follow without some familiarity with the references given. In general, the paper is for theorists rather than design engineers, since much more work is needed to prove or disprove the hypothesis.

R68-13833 ASQC 823; 844

DYNAMIC CAPACITY OF OSCILLATING ROLLING ELEMENT BEARINGS.

J. H. Rumbarger (Franklin Institute, Research Laboratories, Friction and Lubrication Labc atory, Philadelphia, Pa.) and A. B. Jones *American Society c brication Engineers and American Society of Mechanical Engi s. Lubrication Conference, Chicago, Ill., Oct. 17–19, 1967.* 9 p. refs. Research supported by the Franklin Institute.

(ASME Paper-67-Lu 22; A67-42680) Members, $0.75; nonmembers, $1.50.

The results of life tests of 388 caged, needle-roller bearings under combinations of load, speed, and amplitude of oscillation are analyzed with Weibull statistics. The rolling bearing theory of Lundberg and Palmgren is extended to cover oscillating roller bearings and is favorably compared with the life tests. A formula for basic dynamic capacity in oscillation is developed for amplitudes of oscillation which are less than the critical amplitude. Capacity formulas are also presented for both ball and roller bearings for any amplitude of oscillation. Author (IAA)

Review: Previous caged needle-bearing tests under oscillating conditions have been re-analyzed in an attempt to provide an explanation for the test results obtained. A load-life formula was developed for predicting the effect of load and angle of oscillation on bearing life. This H_{10} life predicted by the formula is compared to Weibull plots of actual test data to establish H_{10} life with 90% confidence limits. In all cases the H_{10} life predicted by the load-life formula fell within the 90% confidence limits on H_{10} life found from the tests. The analysis, however, is limited to the actual bearing tested. Correlation with other bearing sizes and geometry was not attempted. The major portion of the paper covers the development of the load life equation for needle bearings as based on Lundberg–Palmgren theory for roller bearings. As a result, the paper is not easy to read and follow. It does, however, make a major contribution in an area where very little information seems to be available.

R68-13834 ASQC 824

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

A PROBABILISTIC INTERPRETATION OF MINER'S RULE

Sam C. Saunders and Z. W. Birnbaum (Washington Univ., Seattle). 30 Apr. 1967 32 p refs *Its* Mathematical Note 505

(Contract Nonr-477(38))

(D1-82-0603; TR-49; AD-652419; N67-33105) CFSTI: HC $3.00/MF$0.65

Miner's rule for the cumulative damage due to fatigue, the behavior of which is well known in engineering practice as a deterministic rule, is examined from a probabilistic point of view. By adopting a model for stochastic crack growth with incremental extensions having a distribution with increasing failure rate, and utilizing some results from renewal theory, we exhibit conditions of dependence upon load under which Miner's rule does yield the mathematical expectation of the fatigue life. We also obtain conditions of dependence under which it is conservative and others when it is unconservative. The relationships between the mathematical assumptions which govern when the rule is, on the average, *conservative or unconservative, are related to the* physical conditions in practice which are known to force significant departures from the rule. Author (TAB)

Review: The theory of cumulative damage has been extensively investigated in the field of metallurgy; it has been virtually neglected, except for the linear hypothesis, in electronics. All of the efforts, however, suffer from a meager theoretical foundation and this paper is an effort to help fill that breach. Several stochastic models of cumulative damage due to fatigue are considered together with their relationship to Miner's rule. The derivations are mathematical with renewal theory and increasing failure rate theory being the main tools used. It is especially pleasing to see the stochastic model related to the physical mechanisms of fatigue. The authors are quite careful to point out under what circumstances Miner's rule is approximately correct (i.e., gives approximate expected fatigue lifetime) and under what circumstances it is conservative or otherwise. This paper will be of little use to practicing design engineers, but will be of great value to theorists who will need to assimilate this work and will want to extend it. The casual reader may have difficulty following some of the notation and arguments, but this is the price of progress.

R68-13835 ASQC 824

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

MAXIMUM LIKELIHOOD ESTIMATION OF A U-SHAPED FAILURE RATE FUNCTION

T. A. Bray, Gordon B. Crawford, and Frank Proschan Oct. 1967 44 p refs *Its* Mathematical Note No. 534

(D1-82-0660; AD-663678; N68-18075)

A maximum likelihood estimate (MLE) is derived for the failure rate as a function of age based on incomplete data, assuming the failure rate function is initially decreasing and subsequently increasing, with the turning point unknown. An algorithm for computation of the MLE is developed; a small worked example is included to show in detail the steps of the algorithm. A program for machine computation is presented. The MLE is shown to be a consistent estimator. No further assumption is required as to the mathematical form of the life-length distribution (such as exponential, Weibull, normal, etc.). Thus the model may be realistically applied in a variety of reliability situations, where the so-called bathtub shaped failure rate is appropriate. In the present paper it is applied to the analysis of airplane part failure data. A *real life large-scale example* is presented in which the failure rate of a constant speed drive unit of a jet airplane is estimated. Author (TAB)

Review: This report solves the very important problem of estimating (by maximum likelihood) a general U-shaped failure rate function—no other assumptions concerning the life-time distribution are made. Thus the method could be called "non-parametric." It should be noted that the term "likelihood" used here is slightly different from that notion as it appears in introductory statistics

texts. This intuitive criterion is certainly still appealing and, as the report shows, leads to an estimate which is "strongly consistent." It should also be emphasized that in most practical problems the computations necessary to find the estimates will require use of machine computation. Worked examples together with detailed mathematics and computer programs make the report extremely useful.

R68-13836 ASQC 824
California Univ., Berkeley. Operations Research Center.
TESTS FOR MONOTONE FAILURE RATE BASED ON NORMALIZED SPACINGS.
Peter J. Bickell and Kjell A. Doksum Sep. 1967 44 p refs
(Contracts Nonr-3656(18); Nonr-222(83); N00014-67-A-0114-0004)
(ORC-67-37; AD-661828; N68-15517)

Let x sub (1) < ... < x sub (n) be the order statistics of a random sample from a population with density F and distribution function F such that F(O) = 0. Let Q(T) = F(T/(1 − F(T)) be the failure rate of F. In testing H sub 0: Q(T) = lambda vs. H sub L: Q(T) vertical arrow, Proschan and Pyke (Vth Berk. Symp.) considered certain statistics based on R sub L, ..., R sub N, the ranks of the normalized sample spacings D sub I = (N − I + L) (X sub (I) − X sub (I − L)), 1 = or < I = or < N, X sub (O) = 0. They show that these statistics are asymptotically normal for fixed F and compute the efficacy of one of these statistics for selected distributions. This report shows that asymptotic normality holds also for sequences of alternatives approaching H sub O as N approaches infinity and conclude that the above efficacies yield Pitman efficiencies. TAB

Review: This is a very mathematical paper on the whole and an understanding of the proofs will require a substantial background in mathematical statistics. For one who can sort them out, the results are quite interesting and tables of the power functions (obtained by a Monte Carlo technique) can be especially useful. The interested reader should also consult the paper covered by R68-13730.

R68-13843 ASQC 824
RELIABILITY GROWTH AND ITS UPPER LIMIT.
E. P. Virene (Boeing Co., Seattle, Wash.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 265–270. 6 refs.
(A68-19508)

The paper presents a useful method of estimating reliability growth and its upper limit and shows examples of the application of this method to the Lunar Orbiter spacecraft and Blue Scout launch vehicle data. An excerpt is included from a table to illustrate computation, and mathematical model is given in support of the method. The confidence associated with the reliability in the case of the launch vehicle is given. Author (IAA)

Review: This paper sets forth a step-by-step method by which design engineers can calculate future reliability growth of a device using the Gompertz equation. An inherent assumption is that the Gompertz equation is an appropriate one for describing the reliability growth. The three parameters of the model are estimated using the least squares procedure on the logarithm of the reliability (r). It should be noted that fitting the logarithm of r instead of r will result in slightly different estimates of the parameters. It is possible to use direct non-linear least squares techniques with the values of r and obtain the estimates of the parameters by an iterative procedure. The four examples given in the paper do contain some rather remarkable comparisons between the calculated reliabilities and those given by the data. The reader is cautioned that extrapolation very far beyond the last time for which a data point is available could lead to considerable error. A large number of parametric models have been considered in the literature. The Gompertz equation is only one of several such models. It is not evident at this time which of these models will have more general application to real-world problems. This paper contains only a few of the references which would be of interest to design engineers concerned with reliability growth. For other papers on this topic see R63-10895, R66-12476, R66-12663, R66-12772, R67-12981, R67-13060, R67-13101, and R67-13103. This paper should be of interest to readers concerned with reliability growth as it does provide a very simple cookbook procedure for estimating the parameters of a Gompertz curve. However, these parameter estimates may suffer from the difficulty mentioned earlier in the review.

R68-13845 ASQC 824; 844; 851
HOW ACCURATE ARE RELIABILITY PREDICTIONS?
Anthony J. Feduccia and Jerome Klion (USAF Systems Command, Research and Technology Div., Rome Air Development Center, Griffiss AFB, N. Y.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 280–287. 8 refs.
(A68-19510)

Evaluation of accuracy of stress-analysis reliability prediction techniques. Methods are described which can be used (1) to compute confidence intervals about a predicted value and (2) to advantageously derive reliability demonstration plans that can reduce test time. IAA

Review: The approach in this paper is a good one, namely that of trying to find the frequency distribution of the ratio of predicted to observed mean-time-between-failures, then using that information as an a priori distribution for a Bayes estimate. The authors analyze a few pitfalls of their particular set of data and give a reasonable analysis of it. Questions for further research might be (1) how to extend this for other than fixed ground environments, (2) deciding if the location parameter in the gamma distribution is really necessary or if 0 would not do as well or better (since it is simpler), (3) deciding between the gamma and the logNormal distributions, and (4) finding other parameters of the equipment or use so that the variation of the ratio can be reduced. The paper inadvertently illustrates the disadvantages of the Chi-square test and its low power of discrimination: two different distributions were accepted as representing the data, not because they both did so well but because the power of discrimination of the test was low. It would have been helpful if some of the calculations had been carried through before substituting the numbers rather than afterwards. Trying to follow the numerical calculations is much more difficult than following the algebra. The approach described in this paper does not solve the difficulties associated with predicted versus actual reliability, but it does help in handling them.

R68-13857 ASQC 824; 433; 612
BAYESIAN CONCEPTS FOR RELIABILITY AND CONFIDENCE.
George J. Schick (Southern California University, Los Angeles, Calif.; McDonnell Douglas Corp., St. Louis, Mo.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 397–405. 20 refs.
(A68-19520)

Comparison of the classical and Bayesian approaches to reliability estimation of complex systems at a specified confidence level. While the basic assumptions are clearly stated for either of the two approaches, and while the two methods differ considerably, the philosophical questions underlying the assumptions are not discussed. The treatment is fairly mathematical, but examples from actual applications are such that the practicing reliability engineer as well as the reliability manager can follow the discussion. Some of the misuses of Laplace's rule of succession are given through practical examples, and ways of avoiding these pitfalls are indicated. The Bayesian method and its appropriate computer program for finding exact confidence limits for the system reliability of complex missile systems is discussed in detail. IAA

Review: This paper reviews the state-of-the-art concerning both the classical and the Bayesian approach for obtaining reliability of complex systems on the basis of subsystem reliability tests. The major contribution of the paper is in the detailed discussion of the Bayesian method and a computer program for finding exact confidence limits for the system reliability. Those interested in the program should refer also to the author s Reference 17. Nineteen other references are given in the paper and a brief description of the work of many of these references is provided. This is a mathematical paper; however, it is written so that people having interest in the subject of Bayesian application and some of the classical methods will find it helpful. The paper is well-written; however, there are a few typographical errors such as a confusion of capital X's and small x's on page 401 and the use of a slant instead of a vertical line for conditional probability notation.

R68-13858 ASQC 824
RELIABILITY ASSESSMENT IN THE PRESENCE OF RELIABILITY GROWTH.
A. J. Gross and M. Kamins (RAND Corp., Santa Monica, Calif.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 406–416. 11 refs.
(A68-19521)

Suggestion of four reliability growth models or patterns for weapons systems that can be fitted to actual experience data to discern the quantitative characteristics of the growth within relatively well defined tolerances. This objective is achieved by defining appropriate parametric models and subsequently using maximum-likelihood procedures to obtain estimates of the parameters, and hence of the reliability. The models are studied in detail with regard to their ability to meet sufficient conditions for the existence of maximum-likelihood estimators. It is shown that only two of them yield maximum-likelihood estimates that can be used under the most general circumstances. Numerical procedures are developed for obtaining the estimates of the parameters. The variance–covariance matrix of the estimates is used to construct approximate confidence regions. The models are compared with each other and with alternative nonparametric and Bayesian approaches, using simulated data to make the comparisons. IAA

Review: The purpose of this study is to explore the utilization of various parametric reliability growth models in evaluating current reliabilities and predicting near-term future reliabilities of complex weapon systems that exhibit reliability growth during their development. The authors seem to achieve this purpose. The comparisons made using a certain growth model as input and another model in the analysis indicate biases as expected. It would be preferable to compare the mean square error of the predictions in order to have an overall measure of the sensitivity of the model to various inputs. The conclusion that the predictions do not seem to depend upon the model is probably a result of the fact that one is only predicting for the first stage beyond the first seven stages of input. Hence, the extrapolation error will be rather small. This paper should be of interest to reliability engineers who are concerned with using growth models. However, some of the results are not easily followed. The reader interested in the subject of reliability growth models should refer to some of the references included in the paper; in particular, Ref. 2 (see R66-12772 and R67-13060) gives a discussion of several parametric growth models, and Ref. 8 (see R63-10895) gives some of the mechanisms which indicate the feasibility of using such models. For other papers on reliability growth see R66-12476, R66-12663, R67-12981, R67-13101, and R67-13103.

R68-13859 ASQC 824; 844
THE DETERMINATION OF THE PROBABILITY OF FAILURE BY STRESS/STRENGTH INTERFERENCE THEORY.
Ralph L. Disney (Michigan University, Dept. of Industrial Engineering, Ann Arbor, Mich.) and Narendra J. Sheth (Michigan University, Dept. of Mechanical Engineering, Ann Arbor, Mich.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 417–422. 5 refs.
(Contract AF 30(602)-3684)
(A68-19522)

Demonstration of the possibility of using several methods to determine the probability of failure of a part which is subject to a stress Y and which has a strength X, both of which are random variables, when the probability-density functions of X and Y are known. Each of these methods is illustrated for several cases of interest, including: (1) normally distributed strength and stress; (2) gamma-distributed strength and stress; (3) Weibull-distributed strength and stress; and (4) Weibull-distributed strength and normally distributed stress. It is shown that the probability of failure can be computed in terms of well known functions for cases (1) and (2). To find the probability of failure in cases (3) and (4), an integral must be numerically evaluated. It is noted that tables of the probability of failure have recently been compiled to cases (3) and (4). IAA

Review: The simple stress-strength theory of failure, sometimes called inference theory, is not very complicated in principle, but in practice the evaluation of the probability of failure can be rather tedious, as shown by the authors. The mathematics in the various examples was not checked; anyone who is interested in these specific examples will probably work through them anyway. It is noted that the case in which both the stress and the strength distributions are logNormal is not included in the paper. An easy analysis results in this case because the inequality $X \leq Y$ is equivalent to $\log X \leq \log Y$. Thus if X and Y are logNormal then log X, log Y and log X–log Y, are normally distributed. Unfortunately a similar approach does not result in a tractable formula for the probability that $X \leq Y$ if both X and Y are Weibull variables. Very seldom are enough good data available to discriminate between two distributions such as the Weibull and logNormal for the material which will actually be used. If the data are few, the statistical power

of discrimination will be low; if the data are numerous, they are not likely to be exactly like the future in-service properties. For example, if one is working with steel beams, the various strength parameters of the distributions for the steel you are getting, and as fabricated into the beams, depend on many factors, virtually none of which will be known very well by the designer. The designer may have very good *historical* data in some area of interest, but those data will probably be a gross approximation to what he really needs. It is worthwhile in any such analysis to get no more complicated than the data require. Therefore, it is sometimes adequate to use a more tractable distribution such as the logNormal rather than the Weibull. Any differences in answers due to the exact distribution assumed will virtually always be much less than the other uncertainties involved in the problem. The paper is a contribution to the theory, and by making the use of various distributions easier, will add to the tools of design and reliability engineers.

R68-13860 ASQC 824; 831

PREDICTION OF SYSTEM RELIABILITY BY METHOD OF BOUNDS.

R. B. Amstadter (Aerojet-General Corp., Von Karman Center, Azusa, Calif.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 423–430.

(A68-19523)

Definition of the refinement of a new method of reliability prediction for complex systems. The method involves the calculation of both upper and lower bounds and procedure for combining the two to yield a realistically precise estimate of the true value. The refinement includes the consideration and use of failure modes and then probabilities of occurrence. The method can be used both as an excellent substitute for more time-consuming quasi-exact procedures, and also for those systems for which exact procedures cannot be developed and for which Monte-Carlo techniques are excessively costly. It involves subtracting probabilities of failure cases from unity to obtain an upper bound and adding probabilities of success cases to obtain a lower bound. The bounds can be brought as close together as desired by considering more and more cases, although the complexity increases geometrically as additional cases are included. However, the method of combining the two bounds makes it unnecessary to increase the complexity beyond easily calculated terms. IAA

Review: The calculation of reliability of a complex system is a tedious task even with all of the simplifying assumptions of statistical independence, two possible states for each block, etc. This paper tries to simplify the complex calculations by omitting some of them. The method is reasonable enough, but it is difficult to find the exact algorithm in the paper by which one attacks a complex system in a reasonable manner. Arriving at this algorithm by oneself is impeded by unclear statements. For example, "Hence, system failure probability resulting from failure... of elements of C and E in the ... logic diagram is defined as: $R_A \times R_B \times Q_C \times Q_E$, ...". The failure probability is not defined by this statement, but rather was *defined* by the logic diagram; it is *calculated* by the formula. The condition of elements other than A, B, C, and D is irrelevant as in 1 (a) below. Apparently the intended algorithm is as follows: 1. List all the elements (across the page) and write an abbreviated truth table. There are two kinds of abbreviation, described as follows. (a) Many lines in the table are combined when it is simple to do so. For example, if a series element is failed, the system has failed and there is no point in detailing the remainder of the truth table for that element in the failed condition. In this case one may wish to put in a *zero* for failed, a one for not failed and a *blank* for irrelevant. (b) Omit some lines in the truth table that have a low probability of occurrence. Most of the rest of this algorithm is concerned with how to do that. 2. The table is begun with situations where one failure causes system failure and is abbreviated in the above way. 3. Continue with the case where exactly two failures cause system failure (still abbreviated by combinations). If it turns out to be necessary, the cases where exactly three failures cause system failure can be considered. 4. Start at the bottom of the page and consider not system failure but system success. The first item of course is where zero elements are failed and the system is a success. 5. List all the cases where one element has failed and the system is a success; again it may be possible to abbreviate the table by combinations. 6. Next come the cases for two elements failed and the system still a success. 7. One keeps on this way (alternating between system success and failure) as far as necessary. At each step of the way, the upper and lower bounds on reliability are calculated. It is apparently important to keep the upper and lower bounds "in step" as mentioned in the author's errata sheet. When they are close enough together (which can apparently be determined only by experience) the geometric mean of the two bounds on unreliability is calculated and that used for the system unreliability. When evaluating the table mentioned above, the probabilities for each block are multiplied together across the line. Probability associated with a 1 is Reliability (R), that associated with a 0 is 1-R, and that associated with a blank is 1. The author points out some simplifying techniques when working on the bottom of the table. For example, when only one of the elements is not listed as a success, it is more convenient to multiply numerator and denominator by the reliability of that element, thereby making the arithmetic easier. Obviously one way of achieving experience in knowing when to terminate the approximations is to carry them out to the point where reliabilities calculated for the upper and lower bounds differ by less than the accuracy desired. The author gives another method. The author does not relate this method to the calculation of bounds on reliability by the theory of various kinds of cuts in the system.

R68-13861 ASQC 824; 612

SOLVING COMPLEX RELIABILITY MODELS BY COMPUTER.

Leonard R. Doyon (Northeastern University, Graduate School of Engineering, Boston; Raytheon Co., Bedford, Mass.) and Martha W. Berssenbrugge (Raytheon Co., Bedford, Mass.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 431–448. 11 refs.

(A68-19524)

Discussion of the use of digital computers to solve reliability availability/MTBF (mean-time-between-failure) models of complex systems. Actual-case problems with solutions are presented. For solving mission-reliability, instantaneous-availability, and interval-availability problems, use is made of a method of translating each electronic-system operational state depicted in the flow graphs as differential equations in the time domain. By an iterative computer procedure, solutions in the time domain are obtained without having to transform the expressions to and from the complex domain. The computer program is a double-precision digital program called "DIFF," for solving sets of differential equations with as many as 99 unknowns. IAA

Review: This paper conveniently summarizes computerized approaches for solving for mission reliability, instantaneous

availability, and interval availability, using flowgraphs and transition rate diagrams. The computer programs used in the solutions are normally available at computer installations; therefore, it is usually quite easy to put together programs for solving the problems discussed in this paper. However, it would be of interest to know if the programs used by the authors in the solution of these problems are available to the general public, and furthermore, if the programs are written in FORTRAN or in machine language. The reader should have reasonable skills in mathematics of probability and in its application to reliability problems in order to understand fully the discussions in this paper. The eleven references which are cited will aid the reader in obtaining sufficient background should he require it. One might also refer to the text by Sandler [1] for some basic discussion on transition matrices and the solution of problems presented in this paper. This paper should be of interest to those seeking computerized solutions to new reliability and availability problems.

Reference: [1] Sandler, G. H., *System Reliability Engineering*, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1963.

83 DESIGN

R68-13800 ASQC 831; 612; 871

ASSESSMENT OF GROUND SYSTEM PERFORMANCE AND INTEGRATION OF RELIABILITY AND MAINTAINABILITY WITH SIMULATED SYSTEM OPERATIONS.

John E. Snyder (Boeing Co., Seattle, Wash.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 555–561. Research sponsored by NASA.
(SAE Paper-670672; A67-34694)

Description of an idealized approach to developing design criteria for a ground-support system, assessing system effectiveness, and improving system design. System design starts with mission objectives and performance requirements. As the flight system is designed, the assembly, test, and checkout functions are identified. These generate requirements to be satisfied by the ground system. Requirements are allocated to the system elements as design criteria and provide the basis for ground-system design and procurement. The system is designed and fabricated to these criteria. This approach to requirements and criteria has been applied in part on the Saturn V program., and a simulation of the Saturn V activities at the launch pad has been developed. The most significant results achieved to date are discussed. IAA

Review: This paper gives a brief, "broadbrush," narrative description of one organization's approach to assessment of a ground support system for prelaunch operation. The main ideas will be easily grasped by experienced reliability and systems analysts; however, beginners would have difficulty in comprehension due to lack of detail and continuity in the presentation. Due to the nature of system operation, system availability is a major factor in the assessment. A simulation approach is mentioned but not enough description is given to enable a reader to know precisely what simulation type was used. Some interesting illustrations of results based on real data are given; these show how availability is influenced by improvements in failure rate, repair time, and length of the launch window. The real benefit of an assessment technique is determined by how well it aids in uncovering weak points in the system. Some special ranking schemes are described for this purpose and one approach of determining correlations between event ranking and equipment ranking appears to be especially beneficial.

R68-13805 ASQC 831; 817; 824; 838

RELIABILITY DESIGN ANALYSIS FOR SPACE SYSTEMS.

Stuart A. Weisberg (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 594–599. 4 refs.
(SAE Paper-670677; A67-34698)

Description of some of the problems encountered in the design of space systems with particular emphasis on reliability estimation. A brief description of a computerized technique for estimating system reliability, which has been successfully used on major space projects, is given, and weight-reliability tradeoffs are discussed. A problem encountered in long-duration manned space missions—namely the need for spare parts, redundancy, repairability, and interchangeability of parts—is discussed. IAA

Review: Analysis techniques for three space-oriented problems are introduced in this paper. The problems are of the sort where there are many possible combinations to be considered and thus are best analyzed by means of a computer. There is nothing really new here; presumably the author is calling attention to analysis techniques which he has found to be useful. The discussion of the weight-reliability tradeoff problem in the paper is in terms of Lagrange multipliers. No references on this topic are given and readers interested in pursuing it further should see the items cited in the paper covered by R67-13319.

R68-13808 ASQC 831; 612; 844

AN AUTOMATIC RELIABILITY ASSESSMENT AND ANALYSIS SYSTEM FOR SPACECRAFT AUTOMATIC CHECKOUT EQUIPMENT.

H. P. Nicely, Jr. (General Electric Co., Missile and Space Div., Valley Forge, Pa.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 628–641. 4 refs. Research sponsored by NASA.
(SAE Paper-670681; A67-34701)

The paper describes an operational computerized system which produces automatically many tools useful in the reliability and maintainability surveillance of a hardware project. Some of the tools, such as the flagging of selected assemblies and components, are especially of value in product improvement studies. Other tools, such as reliability and maintainability trend charts produced on a printer-plotter (each with superimposed predictions), are of value in the comparison of actual performance with expected performance. The development of this computerized system was sponsored by NASA specifically for the Acceptance Checkout Equipment for the Apollo Spacecraft (or ACE-S/C). This checkout equipment is being used to monitor Apollo Spacecraft performance at Grumman, at North American Aviation, at the Manned Spacecraft Center, and at the NASA Merritt Island complex. Although the computerized system was designed for a specific hardware project, the surveillance

and product improvement tools used are of such a generalized nature that they would be applicable in other hardware projects, whether intended for earth or space applications. Author (IAA)

Review: The significant features of an integrated system of computer programs for systems effectiveness evaluation are described in this paper. These features include (1) the computations of MTBF's and MTTR's; (2) tabulations, trend charts, and correlation charts on MTBF and MTTR; (3) updating of the statistics on MTBF and MTTR; (4) simulation of the operation of Acceptance Checkout Equipment for the Apollo Spacecraft; and (5) the flagging of potentially troublesome components. A flow chart and sample computer printouts are reproduced in the paper, leading to a clear and reasonably detailed description. The actual programs are not given. The surveillance and product improvement tools described in the paper, although designed for a specific hardware project, are of a sufficiently generalized nature that they would be applicable to other hardware projects. Automatic analysis tools of this kind permit the reliability specialist to be free of the more laborious statistical tasks, and therefore available for the more challenging and important tasks of decision and action.

R68-13816 ASQC 838
Imperial Coll. of Science and Technology, London (England). Electrical Engineering Dept.
RELIABLE COMPUTATION WITH UNRELIABLE ELEMENTS
J. D. Cowan Jul. 1966 17 p refs
(Contract N62558-4256)
(AD-646625; N67-26806) CFSTI: HC$3.00/MF$0.65

The paper discusses computer system designs for operation at any required level of reliability, given unreliable elements. Methods discussed are: control of stationary errors and fault-masking of transient errors. TAB

Review: The purpose of writing this paper is not stated and is somewhat difficult to perceive. The paper is apparently a summary of the state-of-the-art, written on an elementary level suitable for those who are not familiar with the field. As such it does a reasonably good job although some of the language is quite general and the beginner, for example, will not know in what sense the term "codes" is being used—whether additional bits are added to a word which is to be transmitted, whether it is the circuitry for decoding the word to see if the appropriate requirements are met, or both. It is also not clear in the discussion on codes whether the incorrect bits are then to be corrected by the circuitry or whether the calculation is to be re-performed. It is doubtful that beginners will find this easy enough going compared to other available literature to make reading it worthwhile. It is further doubtful that those well versed in the subject will learn much from it.

R68-13824 ASQC 833; 844
ELECTRIC SYSTEM RELIABILITY REQUIRES RIGHT RELAY.
Edward U. Thomas (Grumman Aircraft Engineering Corp., Electronic Standards and Components Group, Bethpage, N. Y.).
(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 210–219.
(A66-37180)

Discussion of the reliability and applicability of relays for aerospace work. The misapplication of relays is held to be responsible for a great many relay failures. The proper selection and use of relays is outlined. IAA

Review: Relays are a much maligned device in the aerospace industry and, as this author shows, there are reasons for it, but no excuses. When applied according to their ratings relays can be extremely reliable, but when misapplied they are even more likely to fail than other components are when misapplied. This is true because of lower safety factors, difficult miniaturization, and the fact that abuses tend to be gross rather than marginal. Many good case histories are presented. Unfortunately the photographs showing the evidence are not reproduced very clearly, but it would be difficult to miss the author's point. Everyone who specifies or designs with relays should be familiar with the contents of this paper. The author presents them ably as he has done under many other circumstances.

R68-13825 ASQC 837
IMPROVED RADAR SYSTEM RELIABILITY BY PERFORMANCE TOLERANCE ANALYSIS.
William H. Sellers (Raytheon Co., Bedford, Mass.).
(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 220–222.
(A66-37181)

Method for determining the effect of storage life on the operation of a system through tolerance variation. The method is applied to a sample electrical system. IAA

Review: This paper deals with well-known, well-established principles, but is difficult to understand for several reasons. 1. It is not clear in Part I just what the author means by "stacking tolerances" and "worst-case combination." For example, what one usually means is that stacking tolerances will give a worst-case, but that this worst-case may not be very likely. This does not appear to be what the author says. 2. In some way or other the author seems to treat storage drift as different from operating drift, but it is not clear just how he does it. 3. There are supposed to be two levels of tolerance; it is not clear how these are determined or used. 4. It is not clear whether the variations are considered to be absolute values or whether they are to be associated with a sign, and, if associated with signs, how they are to be taken. Since this is a fairly standard subject which is well explained elsewhere there is not point in consulting this paper.

R68-13856 ASQC 831; 612; 824
APPLICATION OF A "MONTE CARLO" METHOD TO THE DETERMINATION OF MEAN TIME TO FAILURE OF COMPLEX SYSTEMS.
Donald B. Gilmore (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 391–396.

A Monte Carlo simulation is described for determining the mean time to failure of complex electronic equipment with one or more active or standby redundant elements. A reliability block diagram is set up in Boolean algebra, and the mathematical model is based on this diagram. Both block diagram and mathematical model are presented for a typical system that is then analyzed by the Monte Carlo statistical technique that requires little mathematical know-how. Assumptions implicit to the mathematical models used are that all part types have constant failure rates for the period of time under consideration, the device used to switch in the

second element of a standby pair upon failure of the first will operate, and the nonoperating element of a standby pair will not deteriorate until it starts to operate. Calculation of the mean time to failure is detailed. M.W.R.

Review: This tutorial paper on the Monte Carlo method is reasonably straightforward and understandable, although virtually all of the explanation is in the tables for the examples rather than in the text. One assumption that the author missed is that all failure events are statistically independent. The author states that the method is easily applied with or without the use of a computer to systems of any degree of complexity. The truth of this statement depends, of course, upon what one means by easy and by complex. Many systems are so complex that the analysis is handled only by computer and it is not easy even then. The author might have added a few cautions such as the following. (a) The random numbers being used will very likely be pseudo-random numbers and the generator must have only small correlations between any two numbers. (Most computers have such a subroutine available.) For example, if there are 20 elements in the system and you are making 50 trials, that means that you will need 1000 pseudo-random numbers. It would not be wise at all to use a table with only 100 numbers in it, for fear that unsuspected correlations would cause trouble. (b) One of the big problems in Monte Carlo analysis is getting an algorithm which is sufficiently short so that the computer time will not be inordinately expensive for any reasonable number of trials. For complex systems one should search the literature with regard to helpful hints on this point. (c) Mean-time-to-failure is not necessarily the best figure of merit. The hazard rate is often more suitable when time is on the order of the MTBF of an element. (d) Instead of estimating the time to failure for each exponential component, one can take a fixed time and determine whether each such component has failed or not. In short, this is a primer on the basics of Monte Carlo analysis; it is not a handbook on how to carry it out.

84 METHODS OF RELIABILITY ANALYSIS

R68-13792 ASQC 844; 720; 815
BUILDING IN RELIABILITY.
Charles H. Plyer and William P. Wood (Martin Marietta Corp., Friendship International Airport, Md.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 369–373. 8 refs.
(SAE Paper-670646; A67-34673)

Discussion of the failure mode and effects analysis, critical characteristics determination, safety features, and test equipment complexity as the components of an in-house process control program having special significance in their high payoff in product integrity for aerospace missions. Reliability requirements are used to develop quality requirements for process control and a simple method for in-process data analysis is described. This Reject Pattern Analysis relates the cost of failure to the cost of repair. Data are also given to prove the need for product burn-in and screening. IAA

Review: The theme of this paper is that designers should maintain responsibility beyond engineering release into and throughout the manufacturing process. Reliability requirements should be used to develop quality requirements, and effective use should be made of in-process data. Brief discussion is given of the classification of characteristics, the setting of requirements, and the need for product burn-in or screening. The ideas are reasonable and clearly presented; the paper should be of interest to those concerned with the production of high-reliability equipment. The paper contains a definition of "inherent reliability," which is interesting because this term is so often used by writers in the reliability field without definition, thus leaving the reader to wonder precisely what is meant. The definition given in the paper is "achievable under ideal conditions and potentially present in the design," and the source is identified as MIL-STD-721D. It would seem that, in many practical cases, the assignment of a meaningful numerical value to this concept of inherent reliability would be very difficult if not impossible. This is not a criticism of the paper, because no strong point is made therein for the use of the concept of inherent reliability. The paper is essentially a brief presentation of ideas the implementation of which could lead to higher reliability.

R68-13794 ASQC 844; 872
PHYSICS OF MAINTAINABILITY.
C. M. Ryerson (Hughes Aircraft Co., Culver City, Calif.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 389–392.
(SAE Paper-670649)

An organized scientific approach is presented for the solution of design oriented problems that occur during equipment maintenance. Aspects of materials in design include design for preventive maintenance, degradation from maintenance, cost of maintenance, and critical maintenance items. Cause and effect analysis and special isolation techniques are discussed in terms of finding trouble spots. Application to microelectronics consider design weaknesses and maintenance tools; and space environment applications consider the concept of space maintainability and the thermal/vacuum environment. M.W.R.

Review: The title concept is defined only in the abstract. It, together with the examples, shows that the word physics is not necessarily that subject in which physicists are educated or which they practice. Rather, physics is used in the engineering sense of: eliminating cook-book procedures, replacing them by an understanding of what is actually going on, and paying attention to the details therein. The field of reliability-physics (physics-of-failure) uses the term physics in the same sense. Whether this kind of thing should be called a new discipline is hard to say. Engineers will certainly need more help in understanding what is going on, but they need this in all phases of their work. If we are to create a new discipline every time it is suggested that an engineer understand better what he is doing in a particular area, we will soon have far too many disciplines. The problems the author lists are real ones and do need to be attacked. (In one of the examples, the phrase, "...are made of metals which crystallize..." is used. This particular term is about as "unphysics" as you can get. It is a lay-term which usually means fail-in-fatigue, but apparently the author here takes it to mean lose-tensile-strength-but-retain-ductility). It is doubtful that further papers should be directed toward trying to lay out the framework for the new discipline. Rather they should be directed toward specific problems which engineers are expected to handle and toward showing engineers what are important kinds of details to watch out for.

R68-13795 ASQC 844; 782
PLANETARY QUARANTINE AND ITS CHALLENGE TO MATERIALS RELIABILITY.
E. P. Kozoriz (General Electric Co., Missile and Space Div., Re-Entry Systems Dept., Philadelphia, Pa.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics New York, Society of Automotive Engineers, Inc., 1967, p. 399–404. 8 refs.
(SAE Paper-670651; A67-34677)

Discussion of the problem of manufacturing space vehicles with rigidly controlled cleanliness and biological contamination for missions to other planets. The challenges facing the materials engineer and the techniques of sterilization required by a planetary quarantine are considered. The expected future developments in this field are outlined. IAA

Review: From its title, one might suspect that this paper deals in some detail with the relationship between reliability and the decontamination and sterilization of spacecraft. Such is not the case, however, as only the last two paragraphs in the paper are really addressed to this topic. The rest of the paper discusses sterilization requirements, the need for sterilization, and sterilization techniques. The paper will be of interest mainly to those who want a qualitative picture of the problem. Those with an interest in the technical aspects of reliability and sterilization are referred to the papers covered by R67-13223 and R67-13250.

R68-13806 ASQC 844; 433
RELIABILITY PREDICTION WITH INADEQUATE DATA.
Paul Gottfried and David W. Weiss (Booz-Allen Applied Research, Inc., Bethesda, Md.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 600–607. 13 refs.
(Contract AF 33(615)-3598)
(SAE Paper-670678; A67-34699)

Description of an approach to nonelectronic reliability prediction with inadequate data. The lack of sufficient data creates the need to improve prediction accuracy and to quantify the uncertainty associated with the predictions. The proposed approach was developed for reliability prediction in flight control systems, but its techniques are believed to be broadly applicable. One of the aspects of the approach requires the analyst to combine data from diverse sources and then supplement the facts with judgment stating his (subjective) uncertainties in numerical (preferably distributional) form. This aspect contains a Bayesian viewpoint and its effectiveness is discussed. The other aspect is concerned with providing a common structure for reliability predictions of varying degrees of refinement, corresponding to the various program stages and the resources then available. The method used in this case is the Fault Tree approach originally developed for safety analysis purposes. IAA

Review: Attention is called to two subtopics of reliability prediction in this paper. Readers concerned with reliability prediction will want to be acquainted with both of them. The first is the Bayesian viewpoint, which is receiving increased attention. The other is that of the fault tree approach. The discussion is readable and will help to give those who are becoming interested in these topics a better grasp of them. The paper leans heavily on selected references and readers interested in pursuing these two subjects further may wish to consult some of them.

R68-13810 ASQC 844; 831
SYSTEM SAFETY—A QUANTITATIVE FALLOUT FROM RELIABILITY ANALYSIS.
J. R. Jordan and R. L. Buchanan (McDonnell Douglas Corp., Missile and Space Systems Div., Santa Monica, Calif.).
In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 653–660. 5 refs.
(SAE Paper-670684; A67-34704)

Description of a method for quantitatively evaluating the safety of a system by utilizing existing reliability techniques and data. The premise developed is that crew safety is a special case of system safety. Therefore, the reliability analyses and mathematical models developed to evaluate crew safety are considered applicable to a system-safety analysis. System safety is developed as the probability of successfully completing or safely aborting a given operation or test. The relationship and utility of crew-safety mathematical models, failure mode-effect analyses, criticality analyses, critical items lists, component failure data, and system effectiveness are discussed. The extension, reorientation, and selective utilization of these techniques and analyses to the display of system safety is studied. The advantages of developing system safety from existing technology are outlined, and its quantitative figure of merit is stressed. IAA

Review: System safety can at times be a very important element of total effectiveness; however, it often receives less-than-adequate treatment. It is certainly true, as emphasized by this paper, that much can be learned about system safety from analyses for reliability. A thorough failure mode and effects analysis combined with reliability prediction and followed by a safety criticality analysis can identify and assess many of the safety hazards. As recognized, however, such quantitative analysis does not encompass all existing hazards. It is also noteworthy that the system safety problem is broader than just crew safety during mission operation, but extends to include hazards in testing, transportation, storage, etc. The above points comprise the major ones worth obtaining from this paper. An experienced analyst might grasp some further useful ideas by brief perusal of the tables and figures; however, due to lack of clarity and the need for further editing, more detailed points are difficult to follow. A very obvious oversight in editing was made on the second page where it was stated that "...system safety as a probability equal to the sum of two mutually exclusive events: the probability of a failure and the probability of a safe abort." Even the equation that follows states it as the sum of the probability of operation success plus the summation of all success probabilities for abort. The latter is more nearly correct since it corrects the first probability; however, it ignores the fact that the two events are not mutually exclusive. More clarifying discussion would have been welcomed in connection with Figure 2 pertaining to the summary tabulation of calculations for failure mode and effects analysis and the subsequent criticality and system safety analysis.

R68-13814 ASQC 844
National Bureau of Standards, Washington, D. C.
EFFECT OF SURFACE REACTIONS ON FATIGUE FAILURE
Final Report

T. R. Shives and J. A. Bennett [1967] 18 p refs
(NASA Order R-14)
(NASA-CR-82971; NBS-9488; N67-19962)

The effects of oxygen and water vapor on the fatigue properties of titanium alloy Ti-4Al-4Mn and vacuum melted AISI 4340 steel were investigated by means of rotating beam tests of unnotched specimens in four environments: dry helium, dry air, moist helium, and moist air. The fatigue strength of both alloys was lower in moist environments than in dry environments. Oxygen was detrimental to the fatigue strength of both alloys only in the absence of water vapor. A large number of the steel specimens failed due to fatigue cracks having origins below the specimen surface. Author

Review: This paper presents the results and conclusions of a series of experiments conducted to determine what effect four selected environments (i.e., dry helium, dry air, moist helium, and moist air) will have on the service life to two engineering alloys under a fluctuating load. These tests were conducted utilizing the rotating beam fatigue testing procedure, which is a commonly accepted method for determining the fatigue life of various materials. It would have been interesting, however, had the authors included a schematic diagram or a photograph of their testing apparatus. The conclusions as stated on page 8 appear correct as seen from the results presented in Figure 2 and Figure 3. As noted by the authors, the presence of water vapor has greater influence on the fatigue life of these two materials than does the presence of oxygen. In either event, however, the differences are not great enough to be of concern to a designer.

R68-13822 ASQC 844; 770

AIRPLANE PRE-DELIVERY TEST POLICIES AND SYSTEM RELIABILITY.

Robert R. Dye (Northrop Corp., Northrop Norair, Hawthorne, Calif.).
(Institute of Electrical and Electronics Engineers, Aerospace Systems Conference, Seattle, Wash., July 11–15, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems, Supplement, vol. AES-2. New York, IEEE, Inc., 1966, p. 199–203.
(A66-37178)

The results of a study of predelivery reflight practices and subsequent airplane system reliability are presented and discussed. Since the airplane comprises the most complex single-end item of hardware in the airplane pilot training system, the paper deals solely with the airplane. The study encompassed records of 33 airplanes delivered over a four month period. It was found that, for the corrective action policy in effect, the number of failures observed during the delivery flight was independent of the number of flights before delivery as well as the number of failures experienced on the last flight prior to delivery. In addition, the failure rate of these aircraft in the field during the first 50 flight hours after delivery was found to be independent of the number of predelivery flights. As an extension of this study, the statistical distribution of airplane failure rates during the second 50 hr of postdelivery service was determined, and is presented. The overall MTBF for the group of aircraft studied was 7.46 hr during these second 50-hr periods. Author (IAA)

Review: In these days of super-high reliability it is sometimes forgotten that not all failures are equally serious and that customers, when given the choice of (a) paying for the lower probability of occurrence of noncritical failures or (b) finding these malfunctions themselves, may prefer the latter. This paper illustrates several points which are important to remember in a cost-effectiveness attitude toward reliability. For those who wish to go into this particular problem in detail, the author gives several tables of MTBF as a function of flight experience with each craft. Where repair is not difficult, where the failures are not critical, and where good use can be made of the equipment while these failures are being found, it may well be (as the author indicates in this case) that the customer would prefer to find them himself. No mention is made in the paper of how many of these failures tend to be due to similar defects and whether different manufacturing techniques could eliminate or reduce some of them.

R68-13828 ASQC 844

PREVENTING STRESS CORROSION CRACKING OF HIGH STRENGTH ALUMINUM ALLOY PARTS.

J. D. Jackson and W. K. Boyd (Battelle Memorial Institute, Corrosion Research Div., Columbus, Ohio).
Materials in Design Engineering, vol. 63, May 1966, p. 70–75, 158, 161, 162.

Stress corrosion cracking and the resultant failure of high strength aluminum alloy components are discussed in terms of materials selection, suitable heat treatment, and good design and fabrication practices. High strength alloys are found to be most susceptible to stress corrosion cracking, which is defined as *spontaneous cracking from the combined action of corrosion and* static tensile stress. Grain orientation is discussed as a critical factor in this type of cracking. Stress corrosion resistance of various aluminum alloys are rated, guidelines are included for comparing aluminum alloys for resistance to stress corrosion, and it is noted that the sources of stress are not always apparent. Procedures for minimizing stress corrosion cracking are summarized; and alloy selection, heat treatment, assembly factors, forming practices, machining, induction of compressive stresses, and protective coatings are discussed. M.W.R.

Review: This is an informative, semi-technical paper dealing with the problem of stress corrosion cracking in parts fabricated from high-strength aluminum alloys. This method of failure is not unique to these alloys, and it is not a new problem, but it is an *acute problem of current interest to design engineers in the* aerospace industries. The authors present interesting illustrations, examples, and case histories to show how stress corrosion occurs and how it may be reduced by material selection, heat treatment, design, and fabrication practices. The subject matter is presented in a clear, concise manner; the paper is recommended for general reading, particularly for new design engineers.

R68-13829 ASQC 844; 775

CRACK EVALUATION AND GROWTH DURING LOW-CYCLE PLASTIC FATIGUE—NONDESTRUCTIVE TECHNIQUES FOR DETECTION.

C. E. Lautzenheiser, A. R. Whiting, and R. E. Wylie (Southwest Research Institute, San Antonio, Tex.).
Materials Evaluation, vol. 24, May 1966, p. 241–248.
(A66-29316)

The paper discusses techniques used by the Southwest Research Institute to determine fatigue-crack initiation and propagation, a few of the problems encountered, and some of the results of the low-cycle fatigue crack growth studies. All the work described was performed using commercial ultrasonic test instruments. All vessels being fatigue tested were ultrasonically inspected, using longitudinal and shear-wave techniques, before cycling and at intermittent cycle stages. When a fatigue crack initiated, a shear-wave transducer was affixed to the vessel surface. The plastic wedge was fastened to the vessel, usually with Eastman 910 cement. This transducer was monitored every 500 cycles to determine fatigue-crack growth, or continuously, using a timing console developed by Southwest Research Institute. Techniques to operate ultrasonic transducers under 3000 psi pressure were developed. The section of the transducer behind the piezoelectric face and a short section of the

coaxial cable were encased in a rubber tube filled with transformer oil so as to have zero pressure differential across the face of the piezoelectric element. Propagation rates of fatigue cracks under cyclic loading are shown. These plots show that there is an incubation period required before a fatigue crack is initiated at a high-strain location or a welded crack or other defect propagates as a fatigue crack. This incubation period is quite variable, and as yet the parameters which control the life of this incubation period have not been determined. Author (IAA)

Review: This is a well-written paper which deals with low-cycle fatigue crack growth in pressure vessels. The paper is oriented so that experimental techniques and procedures for determining crack growth are emphasized rather than fatigue results. A few interesting and useful fatigue results are included, however. The material presented is of current practical interest. Test engineers in particular should find the discussions concerned with the use of commercial ultrasonic test instruments informative. The article is suggested for general reading.

R68-13830 ASQC 844; 770
Collins Radio Co., Cedar Rapids, Iowa. Environmental Analysis Group.
OPTIMIZATION OF VIBRATION TESTING TIME TECHNICAL SUMMARY REPORT, 29 JUN. 1964–10 OCT. 1965
I. F. Gerks 15 Jun. 1966 159 p refs
(Contract NAS8-11278)
(NASA-CR-77338; N66-34666) CFSTI: HC$3.00/MF $0.65

A system of equations was developed to scale the vibration levels occurring in a structure subjected to field vibration so that a laboratory test consisting of sine dwell, sine sweep, random vibration, or any sequential combination of these, will cause equivalent fatigue damage in a similar structure. A Miles type analysis was made using the Palmgren–Miner and Corten–Dolan fatigue damage hypotheses. The resulting equivalence equations are based on the specimen's dynamic characteristics, natural frequency and transmissibility with the negative reciprocal of the slope of the damage accmulation curve appearing as the only fatigue characteristic in the equations. A computer program using the Palmgren–Miner version of the equivalence equations was developed. The equations were indirectly validated by vibrating sets of test specimens to the different types of input and comparing the predicted damage to the actual damage. The test specimens were externally damped 6061T-6 aluminum alloy cantilever beams. Four basic investigations were made, one of which was invalidated due to faulty instrumentation. The Palmgren–Miner fatigue hypothesis was found more accurate than the Corten–Dolan hypothesis in the prediction of damage for the three valid tests. Author

Review: This is a technical summary report which deals with laboratory fatigue testing to simulate field failures resulting from vibrations. The experimental results were analyzed using both the Palmgren–Miner and the Corten–Dolan fatigue damage theories; the Palmgren–Miner analyses of the data gave better correlations. But any rational fatigue damage hypothesis could have been used since experimental errors and uncertainties caused larger variations than those due to the choice of fatigue damage theories. The report is a useful reference for investigators concerned with vibrational fatigue failures, but it is not for general reading. The mathematical derivations which are presented were not checked in their entirety. Several typographical errors were encountered, but they do not detract from the usefulness of the report. Reproductions from original copies of the paper are not satisfactory because the photographs are not legible.

R68-13831 ASQC 844; 830
Boeing Co., Seattle, Wash. Aerospace Group.
SOME FRACTURE CONSIDERATIONS IN THE DESIGN AND ANALYSIS OF SPACECRAFT PRESSURE VESSELS
C. F. Tiffany, J. N. Masters, and F. A. Pall Presented at the 1966 Natl. Metal Congr., Chicago, 31 Oct. 1966 16 p refs
(Contracts NAS3-4194; NAS3-6290)

Quantitative use of fracture test data and fracture mechanics analysis in the design and analysis of spacecraft pressure vessels is described, and comparisons are made between various materials to illustrate the relative importance and the relationships among some of the more important factors influencing both weight and reliability. Pressure vessel safety design factors must be selected on the basis of materials required, vessel life expectancy, allowable flaw sizes, and nondestructive inspection capabilities; and it is concluded that linear elastic fracture mechanics provides the best and only practical framework for making selections. Pressure vessel critical flaw sizes are discussed, as is the operational life of both thick- and thin-walled vessels. M.W.R.

Review: This paper's greatest contribution is that it shows how fracture mechanics analysis can be used with fracture data to predict method of failure and service life in thick- and thin-wall pressure vessels. Some familiarity with fracture mechanics is desirable for obtaining good comprehension of the ideas presented; however, much can be gained even by the inexperienced reader because of the lucid manner in which the subject is treated. Basically, failures are due to material flaws. Critical flaw size is discussed in terms of flaw depth, geometrical shape, applied stress, vessel wall thickness, flaw growth rate due to cyclic loading, and relation of flaw size to material weight and factor of safety. Methods for locating and measuring flaws are not discussed. In most cases the reader will be well rewarded for the short time it takes to read this paper.

R68-13838 ASQC 844
PREDICTING INTEGRATED CIRCUIT RELIABILITY VIA FAILURE MECHANISMS.
D. I. Troxel and B. Tiger (Radio Corp. of America, Defense Electronic Products, Central Engineering, Camden, N. J.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 217–225. 4 refs.

A stress survival matrix test and a physical effects analysis program were conducted on monolithic silicon integrated circuits to determine reliability as a function of failure mechanisms. Results indicated that reliability of a properly used circuit was not primarily a function of temperature, power, or shock during usage but rather directly dependent upon screening effectiveness during production, production aberrations that can lead to failure in the field, and life distributions and environmental susceptibilities of units undergoing these failure mechanisms. Failure rate is found to decrease with time as the poor quality units are depleted. A procedure for Modeling Integrated Circuit Effectiveness (MICE) is described that consists of life and acclerated life testing, historical data, and theoretical analysis. Reliability characteristics of integrated circuits as determined by the MICE program are presented; as are the approach to predicting reliability, problems related to applying the procedure, and assuring suitable usage and production control. M.W.R.

Review: This paper has an appealing argument. The extent of the appeal depends on how critically one reads the paper. The idea that semiconductors can be divided into two groups—those

which may at some time fail and those which will never fail—dates back to the time when good semiconductors were first being made; so that phase of the technique is not new. It would be a rare situation where one would get enough experimental data on integrated circuits to distinguish between the author's hypothesis, and, say, a Weibull distribution. There is an error in the paper with regard to the use of λ. The expressions which appear as $\exp[-\lambda(t,T,D,V)]$ should be $\exp[-\int_0^t \lambda(t',T,D,V)dt']$, since λ is defined as a rate (presumably the hazard rate). Where there is more than one failure mechanism, the text implicitly presumes that they are mutually exclusive; e.g., if a capacitor, when it fails, had either too large a change in capacitance or too much leakage, but never both, then the failure mechanisms would be mutually exclusive. It is difficult to see, near the end of the paper, how this situation is different from the one many people have assumed, viz., mutually exclusive failure modes or mechanisms—except for the fact that one group is presumed to have a hazard rate identically zero. (A common but rarely applicable assumption is that failure mechanisms are statistically independent.) Another difficulty in critically interpreting the reasoning is that accelerated tests appear to be denigrated as a method of accumulating information, yet all of the tests run in the stress-survival-matrix could easily be considered accelerated tests. It is also difficult to understand the real import of the statement that the poor items are going to fail because of quality defects, assuming that they are not overloaded; the idea appears to be a tautology. As stated at the beginning of this review, the authors have an appealing point, but further efforts are needed to state the position more carefully, to develop the mathematical and theoretical basis, and to apply the approach to actual microcircuitry, if this appealing point is to survive rigorous examination.

R68-13844 ASQC 844

RELIABILITY DATA FROM IN-FLIGHT SPACECRAFT.

E. E. Bean and C. E. Bloomquist (Planning Research Corp., Los Angeles, Calif.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 271–279.

(A68-19509)

Summary of the results of a larger study to isolate, codify, and analyze the reliability data inherent in the operational records of U.S. spacecraft. The study, completed in March 1967, was performed for the General Electric Co., Apollo Support Dept., in cooperation with NASA headquarters. The total effort included compiling and interpreting operational and historic data for 225 launches from 32 U.S. space programs. The data base covers nearly half of all U.S. spacecraft reported in the open literature at the time the study was initiated (May 1966) and includes both NASA and military launches. Author (IAA)

Review: Most persons concerned with design and development of space systems will gain some benefit from reading this paper. The description of the study is generally clear and very interesting. The results represent an aggregation of experiences from many space programs and spacecraft; however, the actual data used in the analysis are relatively sparse. This does not appear to be a fault of the study, but results from the policies of monitoring, operation and record keeping in the various programs. Incidents having assignable causes were rightly not included in any estimation of failure rate or failure probabilities. The categorization and discussion of assignable causes will be of interest to many persons. In-orbit failure rates and failure probabilities during launch were estimated from failures having nonassignable causes. Estimates are given only for generic categories of hardware elements rather than for specific part and component types. Generally, the failure rates obtained do not appear to differ greatly from failure rates contained in popular sources such as MIL-HBK-217A. It is interesting that the results do indicate that failure rates of capacitors, diodes, resistors, and transistors are somewhat lower than those generally assumed appropriate for space application, as has been postulated many times in the past. It can also be seen from the comparison that fuses, solenoids, and switches exhibited higher failure rates than normally used. Due to the sparseness of the data, the results of this study should not be considered conclusive evidence of the true reliability of hardware elements in space. Its major merit lies in the general indication of the nature of things in space application.

R68-13847 ASQC 844

SPACECRAFT LIFE FOR DEEP SPACE EXPLORATION.

Brooks T. Morris (California Institute of Tehnology, Jet Propulsion Laboratory, Pasadena, Calif.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 298–302.

(A68-19512)

Discussion of the importance of failure-mode control in spacecraft design if system and mission failures are to be prevented. Disciplined design of systems and subsystems, failure reporting and failure analysis, and full use of the national technical resources are essential in such a control program. The failures of Mariner 1 and Mariner 3 are considered briefly. IAA

Review: The author recommends self-discipline and diligence of the design group in failure mode analysis as the keys to meeting the challenge of long spacecraft life. The paper is brief and exhortative in nature, saying in general terms what should be done, rather than going into the details of "how to do it." Some insight into how it has been done for spacecraft is embodied in references 1 and 2 of this paper. The example of the Tacoma Narrows Bridge is good for the purpose of illustrating the consequences of failing to take into account a critical failure mode in a design. The paper will be worthwhile reading for those who need to be convinced of the value of failure mode effects and criticality analysis.

R68-13852 ASQC 846; 612

A MONTE CARLO APPROACH TO SPARES PROVISIONING.

R. L. Sebeny (Collins Radio Co., Cedar Rapids, Iowa).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 350–353.

A computer program using a Monte Carlo approach is described for provisioning spares for a complex system on the basis of their impact on system availability and cost. The Monte Carlo technique permits simulation and analysis of a variety of system configurations and maintenance practices; and the input data required to use the program is greatly simplified by using a computer generated table describing system success as a function of assembly states. The input data is user oriented in that it requires only the knowledge of system operation and maintenance practices. This approach to selecting spares is described for a system that contains redundancy in parallel units or subsystems as well as similar units that can be interchanged or cannibalized; and failed assemblies

are either repaired at the system location or replaced from an off-set depot so that both the system and its spares are continually renewed. M.W.R.

Review: This paper is a good example of how the operation of a complex system can be simulated. It is not clear that the approach in the paper for assigning success or failure to each unit is the same as would be obtained by generating a random number for each unit and then using this random probability to determine the success or failure of each unit according to the unit's hazard rate. The latter method is the obvious brute-force one and possibly is equivalent to the one shown in the paper for which, apparently, many fewer random numbers are generated. Perhaps some of the difficulty would be alleviated if Equation 4 in the text were clear; as it stands it is incomprehensible. It is also not clear just what the function of the check routine is. It could be implicitly checking to see if the method of assigning random numbers, etc. in the text is actually a good method. Other than these points, the beginner will probably find it relatively easy to follow the example.

R68-13854 ASQC 844

FAILURE MODE EFFECTS, AND CRITICALITY ANALYSIS.

K. Greene and T. J. Cunningham (Radio Corp. of America, Defense Electronic Products, Astroelectronics Div., Engineering Reliability Group, Princeton, N. J.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, 374–384.

(A68-19519)

Description of the failure mode, effects, and criticality analysis as developed and applied to spaceflight hardware by the Astro-Electronics Division of RCA. The advantages offered are that all potential failure modes are exposed, their possible causes and associated probability of occurrence are classified and quantized, and their effect on system performance is evaluated. An organized, systematic method for performing this type of analysis is described, together with pertinent considerations regarding the basic underlying criteria, required data, and suggested format. Some simplified, illustrative examples are given. IAA

Review: A description of one organization's approach to failure mode–effects–criticality analysis (FMECA) is presented. The experienced analyst will find few, if any, new concepts in the presentation; however, there are some good examples included on the use of FMECA as a design tool to uncover design deficiencies. The treatment is adequate to serve as a reasonably good tutorial reference. It does not include as much detail nor place as much emphasis on computing failure probabilities and special criticality numbers as some other descriptions in the literature. The greatest value of FMECA, however, is not in computing reliability numbers but in detecting needed design improvements. One of the problems in conducting FMECA is deciding upon the level of detail as things can quickly get out of hand if too much detail is included. Some good rationale is presented in the paper on selecting this level. There is no explicit mention of multiple and correlated failures. These can sometimes be important and a good FMECA should make some provision for recognizing them. Generally, if the failures can be assumed statistically independent, the joint failure probabilities are so low that the effort required for considering such second-order effects is not justified. In some cases, however, a component failure, which alone does not cause failure of the system, may induce failure in another component which may cause system failure. Some of these failure combinations may be revealed in the approach described for considering causes of individual failures. The importance of FMECA is well summarized by the authors with the concluding statement "A Failure Mode, Effects and Criticality Analysis, judiciously adapted and applied, is one of the most important and productive tasks of a complete engineering reliability program." Other descriptions of the FMECA are contained in the papers covered by R67-12939, R67-12940, and R68-13665.

85 DEMONSTRATION/MEASUREMENT

R68-13803 ASQC 850; 870

RELIABILITY AND MAINTAINABILITY CASE HISTORIES.

Anthony Coppola and John E. Daveau (Rome Air Development Center, System Effectiveness and Support Section, Griffiss AFB, N. Y.).

In: Annals of Reliability and Maintainability; Annual Reliability and Maintainability Conference, 6th, Cocoa Beach, Fla., July 17–19, 1967, Proceedings. Volume 6—All Systems Go? Conference sponsored by the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the American Institute of Aeronautics and Astronautics. New York, Society of Automotive Engineers, Inc., 1967, p. 582–586.

(SAE Paper-670675; A67-34696)

Comparison of predicted reliability and maintainability figures of merit with values measured during demonstration tests and those experienced in the field. Five data-processing, two radar, and four display consoles are considered. Results indicate that reliability predictions are generally conservative, possibly due to improvements in parts between the creation of part failure-rate references and their use in new equipment. On the other hand, maintainability predictions were far better than field experience with the same equipment. IAA

Review: The dissemination of reliability and related field data is a worthwhile activity. However, the value of this report would have been increased by the inclusion of more information on the characteristics of the equipment, such as their complexity, and whether or not they were through their burn-in period in both the demonstration tests and the actual field experience. Presumably the statistical analyses are based on the assumption of a Poisson process, but no test, statistical or otherwise, is cited to verify whether the Poisson process was appropriate. The approach to the test was that of statistical demonstration using least possible test time. Comparing the results of these tests with later field measurements leaves one with a feeling of uneasiness. The authors feel that longer test times are appropriate. Another approach which is not cited in the paper is the actual use of early field operational results as part of the reliability demonstration.

R68-13812 ASQC 853

AIRBORNE INSTRUMENTS LABORATORY'S ORAL MALFUNCTION REPORTING SYSTEM.

Richard C. Aitken (Cutler-Hammer, Inc., Airborne Instruments Laboratory, Reliability Dept., Mineola, N. Y.).

Evaluation Engineering, vol. 7, Jan.–Feb. 1968, p. 38–40, 45.

A malfunction reporting system that depends upon oral communication is considered to be successful and to elicit greater quantities of usable information because it eliminates (1) use of ambiguous codes, describing types, causes, and symptoms; (2) time delay between generation of the malfunction report and receipt by the reliability engineer; and (3) loss of identity as a malfunctioned piece of equipment during reprocessing. Oral communication is achieved by telephoning a malfunction report to a central point

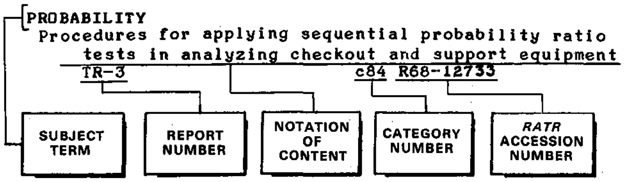
according to a set procedure. Typical flow of the reporting system is illustrated, the call-in procedure tag, and other report documents are illustrated. Malfunction number stickers preserve traceability from previous malfunctions so that results can be sent to the reliability department. M.W.R.

Review: The task of getting complete failure reports is never-ending, especially for those who try to devise systems that will work when the operator does not feel that his main purpose in life is to fill out the report. This paper represents another in the effort to make the reporting easy enough so that the operator will actually do it. It is confined, obviously, to in-house testing since it involves calling a particular extension, which activates a tape recorder, and then giving the information verbally instead of having to write it down. This system might remove some of the inertia involved in an operator's making a report since, as the paper states, it is easier to say something than to get the paraphernalia together to write it down properly. No mention is made of the amount of effort necessary to transcribe the oral reports into a useful form, but presumably that effort is small compared to the value in increased information. (The author in a private communication has indicated that a typist, after an initial breakin period, can average transcribing 10 malfunctions an hour, and that the time saved by the technician offsets the typist's transcribing effort.) Those in engineering or management who must design failure reporting systems should be aware of this one and see where, if at all, it can fit into their own systems.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 6

Typical Subject Index Listing



The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

A

B

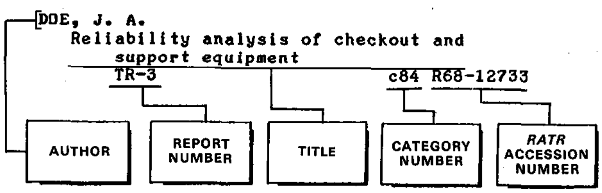
C

S

PERSONAL AUTHOR INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 6

Typical Personal Author Index Listing



The category number and the *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

REPORT AND CODE INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 6

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB*, *STAR*, and *IAA*, respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

ACCESSION NUMBER INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 6

List of *RATR* Accession Numbers

This list of *RATR* accession numbers may be used to identify the category in which a numbered abstract-review appears in the abstract section of this journal. Accession numbers are arranged in ascending order. Preceding each accession number is the category number for locating the abstract-review in the abstract section of *RATR*.

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Reliability Abstracts and Technical Reviews

JULY 1968

Volume 8
Number 7

R68-13862—R68-13914

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

***RATR* ACCESSION NUMBER**	R68-12733 ASQC 844; 413	**ASQC CODES**
	General Equipment Company, Banville, Calif.	**CORPORATE SOURCE**
TITLE	**RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT**	**PUBLICATION DATE**
AUTHOR	John A. Doe 23 Sep. 1966 27 p refs	
CONTRACT OR GRANT	(Contract NAS15-13411)	***TAB* AND *STAR* ACCESSION NUMBERS**
REPORT NUMBER	(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65	**SALES AGENCY AND PRICE**

***RATR* ACCESSION NUMBER**	R68-12739 ASQC 814	**ASQC CODE**
TITLE	**SEMICONDUCTOR RELIABILITY**	
	Joseph A. Smith (Eastern University, Arlington, Penn.)	**AUTHOR AND AFFILIATION**
JOURNAL REFERENCE	*Electric Journal,* vol. 8, Apr. 1966, p 478–492.	
	(A68-12569)	***IAA* ACCESSION NUMBER**

***RATR* ACCESSION NUMBER**	R68-12765 ASQC 773; 221; 823	**ASQC CODES**
TITLE	**TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES**	
	Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)	**AUTHORS AND AFFILIATIONS**
CONFERENCE OR SYMPOSIUM REFERENCE	*Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p*	
	Available from Assoc. of Reliability Eng., New York: $1.00	**AVAILABILITY AND PRICE**
***IAA* ACCESSION NUMBER**	(A68-12407)	

VOLUME 8 NUMBER 7

Reliability Abstracts and Technical Reviews

A Monthly Publication
of the National Aeronautics and Space Administration

July 1968

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13875 ASQC 810; 833
Martin Co., Baltimore, Md.
PARTS AND MATERIALS APPLICATION REVIEW FOR SPACE SYSTEMS
J. P. Craig, R. E. Boss, and S. J. Henkel, Jr. Washington, NASA, 1967 58 p refs Prepared for NASA
(NASA-SP-6505; N68-10120) CFSTI: HC$3.00/MF$0.65

Parts and materials application–review activity for project management of space systems is defined, and a guide for performance of effective reviews by parts and materials specialists and design engineers is provided. Parts application review is necessary with regard to: flammability and outgassing properties of parts; compatibility of leads with metal joining processes; compatibility of parts surfaces with coating and encapsulants; and environmental resistance and physical and electrical properties of coatings, encapsulants, and insulating materials. A method for selecting the scope of review activities appropriate to various levels of project requirements is illustrated by examples of projects and their hardware. S.P.

Review: Although this document is titled and introduced as an application review, it contains about as much material on the technical features of a parts and materials program as on reviewing a program. The inclusion of parts and material technical program activity is fortunate, since although reviews are most important in the checks and balances of high reliability activity, they can be a very dry subject. This document is keyed to NASA reliability publication NPC 250-1; it is, therefore, a permanent reference item for a NASA contractor and will also be of interest to anyone concerned with high-reliability programs or with design review. The technical and illustrative details have an electronic orientation, although the review elements are quite general. Analogous reliability activity guidance documents are the items covered by R67-13367, R68-13560, and R68-13592.

R68-13884 ASQC 810
THE FRONT OFFICE LOOKS AT RELIABILITY.
I. K. Kessler (Radio Corp. of America, Defense Electronic Products, Camden, N. J.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 449–451.

A management philosophy that is aware of the personnel and other needs for high reliability implementation is stressed, along with a management policy that follows up reliability needs. Training of design engineers is emphasized, as is determining the roles of designers and systems analysts so that reliability goals can be achieved. Effective interplay and communications among the functions and people responsible for quality, design, cost effectiveness, and other elements of the production process is considered a must. M.W.R.

Review: There have been many appeals in the literature for top management understanding and support of reliability activities. The "front-office" viewpoint given in this paper is not so different from that often given in the literature by knowledgeable reliability managers and specialists. It does well in summarizing briefly many key points on the importance and successful implementation of reliability activity and serves as a good reminder to reliability personnel that they too have responsibilities—not only in auditing reliability but also to be creative. Although not stated in the paper, effective communication is an important factor serving as common denominator to many of the points discussed. This communication involves not only top management and reliability but all elements of the organization. A good appeal is made for practicality with respect to costs and schedule. The paper contains a number of annoying typographical errors; however, the message makes the paper worth the few minutes it will take to read it.

R68-13887 ASQC 810
THROUGH THE LOOKING GLASS.
H. A. Stone (Bell Telephone Laboratories, Inc., Whippany, N. J.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 470–476

A design engineer's point of view toward reliability engineering is presented; and functions of a reliability engineering center are discussed in terms of the organizational, technical, and human problems. Primarily, such a center should develop and advance skills required to meet the demands of modern systems, make or assist others to undertake systems analysis studies relating to reliability, and help to implement corrective action based on failure experiences in the field. A small and closely-knit reliability structure is recommended that will not infringe upon systems and device development activities. M.W.R.

Review; "What good do reliability organizations do?" This paper is an easily read, sometimes humorous, often perceptive answer to that question. Even though the paper deals with management-type aspects of reliability, it bears little relationship to the stilted non-real-world discourses one often finds on that subject.

Not everyone will agree with some of the points, especially since the author often forms a caricature to help in making his point. (The paper will have little value as a reference.)

R68-13890 ASQC 814
THE IMPACT AND STRUCTURE OF LIFE CYCLE COSTING.
N. C. Stordahl and J. L. Short (Collins Radio Co., Cedar Rapids, Iowa).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 509–515.

While it is not considered feasible to implement life cycle costing on every DOD procurement, particularly in the case of concept formulation and study programs, there are benefits to be gained by any end item manufacturer who is willing to analyze his products for total lifetime cost. Life cycling costing techniques are considered equally applicable to commercial and military users, and both the development of the life cycle cost structure and the cost accumulation process lend themselves to automation. Both customer and contractor must realize the magnitude of the data exchange program involved in implementing life cycle costing; and, when properly implemented and managed, life cycle tradeoff analyses can become the catalyst for design, support, and end user to guarantee functional systems that can operate with minimum manpower, material, and money resources. The life cycle costing structure must be all inclusive without being redundant, permit the comparison of bidders on an equal basis, and be flexible enough for the necessary tradeoff analyses. A life cycle cost decision table is appended. M.W.R.

Review: This paper consists mainly of identification of the major elements which make up total life-cycle costs. It will make good material for check-off use. Structures other than the one cited in this paper are possible and are used. The paper is rather broad in scope and does not get into fine points or problems. A broad problem which is cited in the paper is indeed a key one, namely that the onus is on the customer to get bidders on a common data basis so that alternate bidders can be evaluated properly.

R68-13895 ASQC 817
RELIABILITY TRADEOFFS DURING CONCEPT FORMULATION.
Neil J. Scarlett (ARINC Research Corp., Western Div., Santa Ana, Calif.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 576–584. 6 refs.

Techniques for conducting tradeoffs involving reliability during the concept formulation phase are considered, with emphasis placed on identifying the parameters of interest, quantifying reliability in terms of these parameters, and integrating the results to achieve maximum cost effectiveness. It is concluded that reliability tradeoffs must be based on total life-cycle cost; and that the sensitive parameters for predicting optimum equipment or system reliability are complexity, environment, maintainability, modularity, degree of design conventionality, deployment quantity, useful life, and utilization rate. The tradeoff procedure is detailed; as is the quantification of technical, economic, and military feasibility. Mechanics involved in performing reliability tradeoffs for a shipboard electronics system are illustrated, including the equation that relates reliability and life cycle cost, reliability versus maintainability tradeoffs, and feasibility tradeoffs. M.W.R.

Review: An overview is given of the scope of reliability tradeoff activity during concept formulation. This is a polished paper. It reads well and is nicely illustrated. It seems to be at least in part excerpted from a report or manual, but no direct references are made. A table in the paper (Table 2) identifies the parameters in "basic estimating relationships significant in performing reliability tradeoffs." Unfortunately many of these relationships are not known; therefore, a reliability tradeoff analysis must still contain a large element of human judgment. The tradeoff procedure outlined briefly in the paper will help to focus this judgment.

R68-13896 ASQC 813; 814
REALISTIC RELIABILITY FOR THE COST CONSCIOUS PROGRAM.
Peter B. Brigham (Martin Marietta Corp., Aerospace Group, Orlando, Fla.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 585–592.
(A68-19532)

Examination of reliability program phases and task grouping with respect to the program cost. Some typical reliability program features are discussed, and consideration is given to the selection of program scope. An example is presented in which the optimization of field test and part reliability are illustrated. Input and output data are analyzed, and such operations as verification, standardization, application, packaging/interconnection, and manufacturing are investigated. IAA

Review: A sensible approach to planning reliability programs is presented in this paper. The technical or engineering tasks are emphasized rather than the managerial viewpoint. A key feature of this checklist-approach is to use only the minimum methods which are needed to do the job. The engineering tasks which are mentioned are the usual ones. A computer program is cited as being used to assist in the planning; no details or references are given on this. However, in a subsequent private communication the author has indicated that a complete description of the program can be found in Martin–Marietta Corporation Orlando Division Report, OR 9123, dated November 1967. This document is available through the Orlando Division's Technical Information Center.

R68-13907 ASQC 814; 831; 871
COST EFFECTIVENESS, SYSTEM EFFECTIVENESS, INTEGRATED LOGISTIC SUPPORT, AND MAINTAINABILITY.
Ben S. Blanchard (General Dynamics Corp., Electronics Div., Maintainability Section, Rochester, N. Y.).
(IEEE Transactions of Aerospace and Electronic Systems, vol. AES-3, Mar. 1967, p. 186–194.) IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 117–126. 17 refs.
(A68-18423)

Outline of the basic elements associated with cost effectiveness, system effectiveness, and integrated logistics support. The interrelationships of these concepts are reviewed, and the discipline of maintainability—a major element of each concept—is examined. Maintainability is defined as an effective mechanism for the accomplishment of planned maintenance during the early design and development phases of a system. IAA

Review: There is a plethora of names for various figures of merit of a system which have to do with the system's working (a) when it ought to, and (b) as well as it can when the resources are limited. Even the relatively simple concepts such as reliability or maintainability are difficult enough when applied to complex systems which can have many states between complete success and complete failure. The mind fairly boggles when cost-effectiveness and systems-effectiveness are applied to tremendously complicated and large systems. Many factors must have numbers associated with them, yet these numbers are most uncertain; but where is this uncertainty taken into account? Of course the problems do not end there, since obviously one should include more and more factors in the system, i.e., make it larger; so that eventually one tries to make the whole world cost-effective. This paper treats the philosophical aspects of system effectiveness, etc. Many of the difficulties in trying to effect these concepts are mentioned and overall examples for the F-111 program are given. Of necessity these examples use a considerable amount of jargon which, while explained, makes it difficult for anyone not familiar with it to follow the details (the long complicated names would probably be just as difficult to follow without jargon). The impression is given that reliability and maintainability are the core of systems-effectiveness; they certainly deserve a large share of anyone's attention. The author rightly stresses the importance of management attitudes and of proper allocation of effort. The paper will be most useful for those who are interested in an overview.

R68-13908 ASQC 814; 863

RELIABILITY PREDICTIONS AND SYSTEM SUPPORT COSTS.

James E. Lott (Martin Marietta Corp., Martin Co., Logistics Engineering Dept., Orlando, Fla.).

(IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-3, May 1967, p. 382–389.) IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 126–133. 4 refs.

(A67-31256)

Study of the relationship between reliability predictions and system support costs. A case study of predicted reliability, predicted maintenance factors, and actual spares consumption of 53 component boards (printed circuit cards) used in a major item of ground-support equipment for a tactical missile system is reported. This case study illustrates how a system can be undersupported or oversupported, depending on the data used to determine the quantity of spares required. Factors for undersupport and oversupport are computed for the type of hardware included in the case study. These factors may be related to dollar costs. The problems associated with undersupporting or oversupporting a weapon system are briefly discussed. IAA

Review: This paper was covered by R67-13456.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13862 ASQC 824

General Electric Co., Syracuse, N. Y.

STATISTICAL EXPOSITION OF GUIDE MANUAL FOR RELIABILITY MEASUREMENT PROGRAM

David Rubinstein 15 Nov. 1967 55 p refs

(Contract NOsp 65052-T (FBM))

(NAVORD-OD-29304; Add.; N68-85413)

Mathematical models and derivations and statistical theory are discussed in relation to the Navy Guide Manual for Reliability Measurement Program. Components and systems, failure and reliability, and life testing are considered, including the justification of truncated life testing. Statistical inference of system reliability of a series system is developed in terms of estimates relating to component failure rates, inference based on normal distribution, and extensions to systems with redundancy. Taylor's expansion for guide manual estimates, moments of the number of failures and test termination times, expected values of guide manual estimates, and the termwise expansion of one of the values are detailed. A comparison with other methods is included, as is the distribution of upper confidence limits for system failure rates. M.W.R.

Review: This report was developed as an addendum to the Navy's Guide Manual for Reliability Measurement Program, NAVWEPS OD-29304. As such, it is an exposition of statistical methods for inferring the reliability of serial systems with and without redundancy. Situations with redundancy receive less attention than those without redundancy on the assumption that contributions from redundant components to system failure rates are slight. In line with the methods of the Guide Manual, testing is of the truncated variety. Assumptions, which are of the classical type used in reliability, are clearly stated, and their validity is examined in realistic terms. Mathematical derivations are placed in one section (Section 3), so that those who are interested in the practical considerations and not the theory may avoid this section if they wish. Considerable attention is given to approximate lower confidence limits on system reliability for serial systems, for which a variety of methods have been proposed. In the last section of the report, the author gives the results of some numerical investigations of a number of these methods. This is the only reasonable way in which these methods can be compared, since comprehensive analytical comparisons of different methods are generally extremely difficult. This report is clearly written and has a practical orientation which enables it to serve its purpose of motivating, explaining, and amplifying the statistical procedures of the Guide Manual. Apart from that it has value for those concerned with the inference of system reliability because of its discussions of: (1) the model, informal assumptions and their evaluation, (2) the principal ideas underlying the analysis, and (3) the computation of the proposed confidence limits for truncated testing (which can be extended to the other modes of testing). Other commendable features of this report are: (1) the system-environment complexity and generality with which it deals, (2) its simple conceptual basis, (3) the relative simplicity of the required assumptions, and (4) the good accuracy of the methods under the rather moderate requirements of the informal assumptions.

R68-13867 ASQC 824; 844

Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.

RELIABILITY-CONFIDENCE COMBINATIONS FOR SMALL-SAMPLE TESTS OF AEROSPACE ORDNANCE ITEMS

A. G. Benedict 15 Oct. 1967 9 p ref

(Contract NAS7-100)

(NASA-CR-89303; JPL-TR-32-1165; N67-39369) CFSTI: HC $3.00/MF $0.65

Analyses epitomized by the widely-used equation $\gamma = 1 - R^n$ are shown to provide unexpectedly reasonable approximations for small-sample tests of aerospace ordnance items; high-reliability, low-confidence combinations are discussed. Author

Review: Until one gets to the very end of this paper the point is not too clear (a problem which is acute in Section 2). The conclusion that the report reaches (not the one reported in the abstract) is highly satisfactory and in fact should be heeded by many engineers who are careless in this regard. Essentially the conclusion is that the confidence and the reliability should be on

the same order when you are trying to estimate something. For example, to be 10% confident of 99% reliability is as pointless as being 99% confident of 10% reliability. The author gives a little table which shows the number of samples to be tested (with zero failures) to demonstrate a given reliability under these conditions; a portion is reproduced here:

Conf. = Rel.	99.99%	99%	90%
Sample size	92,000	455	21

In a private communication the author has stated that he is revising the paper to show that sampling plans, even those with low confidence of high quality, are better than no sampling at all. The lots these plans remove tend to be of poorer quality, so that the lots which remain are of higher average quality than would be the case if no sampling were done.

R68-13868 ASQC 824

EXTENSIONS OF RELIABILITY THEORY UNDER NON-INDEPENDENCE OF STRESSES.

J. R. Duffett (TRW Systems, Cocoa Beach Fla.).

The Logistics Review, vol. 3, Nov./Dec. 1967, p. 5–26. 18 refs.

Independence models are given for the upper and lower limits of the reliability of systems composed of m parallel components or n series components, and in each case the obtained values are as a result of variation of the stresses between flights decreasing relative to the variation of the component strengths. Other independence models are presented that account for the variation of the stresses between flights decreasing relative to the variation of stresses within the flights. If the independence model is assumed but not satisfied, it is concluded that optimistic reliability estimates will be obtained for systems with parallel components and pessimistic estimates for systems with series components. A method of increasing system reliability is noted, the relationship of reliabilities of systems is discussed, and pertinent properties of invariance and statistical robustness are treated. The mathematical model embraces the variation of strengths, stresses within a flight, and stresses from flight to flight. M.W.R.

Review: This paper presents an extension of the results in the author's earlier paper covered by R68-13637. The topic area of these papers is important from both an analytical and an engineering viewpoint. Whereas the earlier paper was essentially a presentation of tables for a special case, this one is of a wider nature and is potentially more useful. It is not absolutely necessary that the reader have the earlier paper, but it would help. The terms "series-parallel" and "parallel-series" are explained better in this paper, having been illustrated only in the earlier paper. The discussion of mathematical modeling and the conclusions and recommendations are of general interest. The qualitative discussion contains some useful engineering guidelines, although not all of them are easy to implement. This is a general-interest item, and it is rather unfortunate that it was not published in a source more likely to be read by typical reliability workers.

R68-13878 ASQC 824

Connecticut Univ., Storrs. Dept. of Statistics.

ROBUSTNESS OF RELIABILITY PREDICTIONS FOR A SERIES SYSTEM OF IDENTICAL COMPONENTS

Clifford D. Leitao and Harry O. Posten May 1967 27 p refs

(Contract Nonr-3292(03))

(NASA-CR-94355; RR-29; AD-654720; N68-24204) CFSTI: $3.00

The present research investigates the robustness of reliability prediction procedures based on the assumption of an exponential failure distribution. A system of n independent identical components in series is considered and a maximal region of robustness, in terms of the shape parameter of the Weibull failure distribution (having mean identical to that of the assumed exponential distribution), is determined. This region of robustness has the property that within this region the use of the exponential assumption will produce a prediction error no larger than the specified level of robustness for the region. Regions are obtained for an unrestricted time period and a restricted time period in which the individual components have a minimum reliability rho(rho = .95, .99). Author (TAB)

Review: An analysis such as this can be helpful to both reliability theorists and reliability engineers. But in using it one should be very careful to realize that an extremely specialized problem has been solved, namely, the mean of the Weibull distribution is forced to be the same as the mean of the exponential function, and the criterion for robustness is an arithmetic deviation on the reliability itself. These are legitimate assumptions and may be useful in many cases, but there are certainly other cases in which they will not be useful. The assumption of arithmetic error on the reliability function is perhaps the most severe. This gives the same effect to a deviation of 0.02 in reliability at base levels of 0.5 and 0.98; obviously there is a big difference. Since high reliabilities are of concern, a useful substitute assumption would be to have the region for robustness be an equal percentage of $1-R$—which is almost the same thing at high reliabilities as having an equal numerical range in $\ln(1-R)$. Thus, while this work appears to be competent as a piece of mathematics, its applicability (as with all mathematics) depends on how well the particular problem being solved fits your needs.

R68-13879 ASQC 824; 431; 837

AN INTRODUCTION OF RANDOM DRIFT PARAMETERS IN RELIABILITY.

Kenichi Majima (IBM Japan, Ltd., Kobe Office, Kobe, Japan).

Electronics and Communications in Japan, vol. 38, 1965, p. 74–83.

A random walk model is used to derive random drift parameters, with the mean value of the fluctuating parameter being proportional to time and the probability distribution represented by a theoretical distribution. When the coefficients of these drift parameters are subsequently chosen as the parameters of life of resistors, temperature characteristics of capacitors, and degradation of tube transconductance, good results are obtained that can be expressed numerically and be applied to the determination of reliability. Reliability prediction with respect to time is discussed as is a method for detecting variations of circuit parameters with the drift parameters for various components. In applying the random walk model to various components, it is stressed that the random drift parameters should not change. It is noted that the random walk model can be used as either a probability model or as a normal additive model. M.W.R.

Review: The unique feature of this paper relative to others concerned with degradation or drift is that the mathematical models which are contained in this paper treat time explicitly. The random walk model is emphasized, although other more conventional approaches are also noted. The essence of the random walk model has been suggested previously by the author—see the paper covered by R65-12017. That paper was concerned with an application, whereas this one treats the theory. It is not readily apparent what advantage the random walk model has over the more conventional one of a continuous time-varying distribution such as Eq. 15 in the paper. This paper serves its purpose as an introduction to random drift. However, readers should bear in mind that the random walk model is apparently more of a pet of one author, rather than a model which is widely used in practice for reliability drift analysis.

R68-13883 ASQC 824; 551

Douglas Aircraft Co., Inc., Santa Monica, Calif. Missile and Space Systems Div.

STUDY OF NONPARAMETRIC TECHNIQUES FOR ESTIMATING RELIABILITY AND OTHER LIFE QUALITY PARAMETERS Final Report

V. K. Murthy Feb. 1968 117 p refs
(Contract NASw-1367)
(NASA-CR-93483; DAC-62180; N68-18499) CFSTI: HC $3.00/MF $0.65

This study was undertaken to carry out a comprehensive investigation of procedures for estimating probability distributions of life lengths, as well as the corresponding probability densities and hazard functions, in situations where little or no information is available on the family of the underlying failure laws. Nonparametric techniques were developed for obtaining estimates and confidence bands for various kinds of samples of life lengths and large-sample techniques are derived and discussed. Discontinuities of the life distribution function correspond to times at which the devices considered are exposed to increased "instantaneous hostility." A statistical test is proposed which makes it possible to determine whether such moments of increased instantaneous hostility are present. Exact small-sample probability distributions as well as the corresponding asymptotic (large-sample) distributions to selected Renyi-type statistics are presented. Extensive numerical tabulations of these distributions are summarized in compact tables. Author

Review: Several nonparametric techniques which are potentially useful in estimating the reliability function of a system if a sample or truncated sample of lifetimes is available are given in this report. A test for discontinuities of the distribution function is also discussed. Although this paper is written at a fairly high mathematical level, and hence would be potentially useful for people with such competence, unfortunately it contains errors and unnecessary complications. For example, the conditions stated for $K(\omega)$ in Eq. (24) are not sufficient to ensure the results that follow. In particular, $\int_{-\infty}^{\infty}|K(\omega)|^{2+\delta}\,d\omega$ need not be finite as stated on page 21. The example $K(\omega) = C|\omega|^{-1/2}e^{-|\omega|}$ where C is the appropriate constant is a counter-example. Some extra condition must be added. The wording of the hypothesis of lemma 2 on page 29 is very misleading since this is precisely the hypothesis for the classical central limit theorem. It would be better to write $V_{n1}, V_{n2}, \ldots, V_{nn}$ instead of what is written. Though the condition used for the validity of this lemma (Eq. (72) in the report) has been used elsewhere, it is unnecessarily strong. It is sufficient to show that $\lim_{n\to\infty} n\,\mathrm{Var}(V_n) = +\infty$. Contrary to line 1 on page 34, the conditions (87) do not imply Eq. (72). Errors of this type throughout the report make it somewhat less useful to the practical statistician than it would otherwise be. It will be of some use to statisticians who are interested in the nonparametric estimation of distribution functions and who can recognize the pitfalls and errors which it contains. It will be of no interest to reliability engineers.

R68-13885 ASQC 824; 414

ESTABLISHMENT OF RELIABILITY GOALS.

W. R. Abbott (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Sunnyvale, Calif.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 452–457.
(A68-19525)

Discussion of the problem of establishing reliability goals where the goals cannot be developed from related previous accomplishments. A method for the rational establishment of reliability requirements, based on the user's actual needs, is described. According to this approach, the system performs some function which can be given a numerical measure. For instance, it may be a collector of information, the measure being the number of bits of information collected; or it may perform experiments, the measure being the number of experiments completed weighted by the quality of performance. A requirement as to what this achieved number must be is set independently of the desires of the experimenter. The experimenter chooses a degree of confidence with which he is to equal or exceed the required number. He examines various system configurations which have the potential of performing the required function. For each configuration, he calculates the probability of equaling or exceeding the required measure, using system reliability as a parameter. Any configuration which meets or exceeds his operation requirements with a realizable reliability is an acceptable design solution to his problem. IAA

Review: A useful approach for establishing reliability goals is described briefly and illustrated in this paper. The main text is essentially a discussion of a simple example, illustrated with many figures. The basis of the mathematical formulation is presented in the Appendix. No references are cited. Decision theory forms the basis of the approach, although this is not mentioned in the paper. Readers who are interested in learning more about it will, therefore, want to start looking under the subject of decision theory. Also, readers with a general interest will want to be aware of the potential applicability of approaches to computation other than that shown in the Appendix, which uses the characteristic function.

R68-13888 ASQC 824; 831; 844; 874

COMBINATORIAL TECHNIQUES FOR FAULT IDENTIFICATION IN MULTI-TERMINAL NETWORKS.

W. W. Happ and E. Sarkisian (NASA, Electronics Research Center, Cambridge, Mass.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 477–485. 23 refs.
(A68-18420)

See R68-13902.

Review: This paper is essentially the same as the one by Weitzenfeld and Happ (IEEE Transactions on Reliability, vol. R-16, Dec 67, p. 93–99) which is reviewed in this issue of RATR. The review of that paper applies to this one also.

R68-13899 ASQC 823

SOME APPROACHES TO RELIABILITY PHYSICS.

Yoshiro Kato and Hideyasu Karasawa (Sony Corp., Color TV Development, Tokyo, Japan).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 607–614. 8 refs.

Life data are evaluated on the basis of a physical model that indicates the relationships among life length distribution, an applied stress, and an initial characteristic value. Statistical methods are developed; and simplified equations are found, assuming that (1) the applied stress follows a normal distribution and (2) applied stress and initial characteristic value are mutually independent. The fundamental equation that describes the relationship between life distribution and applied stress indicates (1) life distribution has a

self-reproducing property with the same shape parameters when applied stress level is varied, (2) a new line for life distribution is parallel to the initial line on a probability graph when the stress level is altered, and (3) the logarithm of the scale parameter of life distribution is a linear function of the applied stress mean. The relationship among the shape parameter of life distribution, applied stress factor, and initial characteristic distribution indicates that the slope of the plotted life distribution line changes when either the variance of an applied stress or the SCV (square of the coefficient of variance) of an initial characteristic value is altered. M.W.R.

Review: This paper is somewhat difficult to follow, partly because of poor syntax and partly because of its organization. It is also difficult to know what conclusions are dependent upon which particular assumptions. Many of the sentences and paragraphs are not clear at best; for example, "although Weibull approximation is widely utilized ... the failure distribution should inherently tend to follow a logNormal distribution ... in view of the nature of the physical model." The report may be of interest to those who are theoretically inclined; it will have little if any value for the practicing reliability engineer. The early discussion on the Arrhenius generalized model is irrevelant since Equation 3 swamps all previous assumptions. Some of the derived relationships are called fundamental, but they are actually quite specialized. Evaluating this paper properly will require considerable work from a theoretician, more, perhaps, than he will care to put into it.

R68-13902 ASQC 824; 831; 844; 874

COMBINATORIAL TECHNIQUES FOR FAULT IDENTIFICATION IN MULTI-TERMINAL NETWORKS.

A. S. Weitzenfeld and William W. Happ (NASA, Electronics Research Center, Cambridge, Mass.).

IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 93–99. 22 refs.

(A68-18420)

A procedure is proposed for identification and diagnosis of faults in multiterminal devices. A combinatorial technique determines the number of x-terminal y-port nonredundant subnetworks which can be generated from a z-terminal parent network. This information is intended to identify and isolate internal faults of the system through an optimal set of external measurements. An elementary tutorial introduction to the terminology and procedures of combinatorial analysis aims to make this account self-contained and useful to the reliability engineer without a specialized mathematical background. Four- and five-terminal devices are examined. The results are so formulated as to yield algorithms for computer-oriented procedures to identify the complete set of nonredundant configurations of a multiterminal network. The flow chart of operations suitable for a computer program is presented. Author (IAA)

Review: Improved automated fault detection and isolation procedures are being vigorously sought by researchers. The basic, logical approach for circuits and devices is to compare test responses with previously-determined responses (singly or in combination) which serve as signatures of either normal or some mode of abnormal behavior. A major problem is concerned with determining which responses need to be considered. This is further complicated if there are many ways in which failure can occur or if there are many different responses to be investigated. The overall problem can thus become extremely difficult with complex networks and devices and is as yet unsolved. This paper is concerned mainly with one important aspect of the problem, viz., the calculation of the number of nonredundant configurations possible with a multiterminal network. A noteworthy contribution is made by developing a computational procedure for determining this quantity. Differing with an opinion stated in the authors' abstract, the reliability engineer without a specialized mathematical background in combinatorial analysis will have great difficulty in understanding the development. However, he may gain some appreciation of the problem by first studying Sec. I, then perusing lightly Secs. II through V (while noting especially the flow diagram for computation in Fig. 3), and finally reading Secs. VI and VII. (A good introduction to combinatorial analysis for those interested in pursuing the subject further is [1]). The details of formulation for the algorithms will be of interest only to research workers. A logical extension of the above procedure is the development of a computational procedure to identify and enumerate the specific terminals involved in each nonredundant configuration. There is a brief discussion in the paper on procedures for doing this. In a private communication, the second author states that these have been developed and have now been reported [2]. He also states that the computer program is available either from the author or from the project COSMIC library of computer programs at the University of Georgia, Athens, Georgia. Additionally, in a practical approach one must be concerned with the specific responses required for each configuration (there may be more than one of them for each), i.e., what response represents normal behavior and what responses represent abnormal behavior for the various possible failure modes. For multiterminal devices it will be essential to apply algorithms, i.e., a rationale, to eliminate most of the configurations and most of the responses. Also in the private communication mentioned above, the author states that further effort for development of procedures for doing this is planned. Other applications of fault detection and isolation techniques are described in articles covered by R66-12856 and R67-13263.

References: [1] Beckenbach, Edwin F. (Editor), *Applied Combinatorial Mathematics,* John Wiley and Sons, New York, 1964. [2] McIntosh, Francis J., Jr., "A computer program for subnetwork enumeration and listing," Proceedings of the Third NASA Microelectronics Conference, Feb. 68, Boston, Mass. (Also NASA Report ERC/CQD 68-601)

R68-13903 ASQC 824; 822

ONE-ORDER-STATISTIC CONDITIONAL ESTIMATORS OF SHAPE PARAMETERS OF LIMITED AND PARETO DISTRIBUTIONS AND SCALE PARAMETERS OF TYPE II ASYMPTOTIC DISTRIBUTIONS OF SMALLEST AND LARGEST VALUES.

Albert H. Moore and H. Leon Harter (Air Force Institute of Technology and Aerospace Research Labs., Wright-Patterson AFB, Dayton, Ohio).

IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 100–103. 7 refs.

One-order-statistic or single-observation conditional maximum likelihood estimators are derived for the shape parameters of limited and Pareto distribution functions as well as for the scale parameters of the Type II asymptotic distributions of the smallest and largest values. The mathematical models are detailed for all three types of distributions, for the exact confidence bounds with known location parameters for the limited and Pareto distributions, and for scale parameters of the Type II asymptotic distributions. Relative merits of one-order-statistic estimators and m-order-statistic estimators are discussed. M.W.R.

Review: This is a good mathematical paper on the estimation of particular parameters of specified distributions by means of one order statistic. By one-order-statistic it is meant that a single observation, for example, the *mth* smallest observation of a sample size n, $m \leq n$, is used to estimate the corresponding distribution parameter. Although the estimators considered are inefficient, such estimators are often chosen for their simplicity. The comparisons of the lengths of the confidence intervals based on the single order statistic with those using all the order statistics are very interesting. In particular, one notices that the lengths of these intervals are not appreciably different from the examples which are given in the paper. This paper will be of particular interest to statisticians and reliability analysts concerned with the estimation of parameters of certain specified distributions by means of order statistics.

R68-13904 ASQC 824; 831; 838
ASSIGNMENT OF PRIORITY IN IMPROVING SYSTEM RELIABILITY.
R. Natarajan (Ministry of Defence, Defence Research and Development Organization, Directorate of Scientific Evaluation, New Delhi, India).
IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 104–110. 6 refs.
(A68-18421)

Discussion of the reliability characteristics of a system of two paralleled radars working in conjunction with two paralleled computers. The system is in "up" stage even if one computer and/or one radar fails. The system failure takes place only when both the computers or both the radars are in failed condition. The distribution of time to system failure and its expectation are derived assuming that the failures occur following Poisson distribution and the repair times follow the negative exponential distribution for these two types of subsystems imposing head-of-the-line priority and preemptive resume priority for the repair process. The results are discussed with reference to numerical examples. It is pointed out that the mean time to system failure is higher when the head-of-the-line priority discipline is adopted for repair of components, especially when the repair times are shorter. IAA

Review: This is a short mathematical paper. The algebra was not checked in its entirety but appears to be competent. Before these results are indiscriminately applied, the system the author has analyzed should be clearly put in mind. For example, each component is either good or bad; the time to repair any component is not known (if a tube were to burn out in a transmitter and it is known that it takes five minutes to replace it, then this kind of failure is not considered); the figure of merit is mean-time-to-system-failure. Therefore the results of this study should be applied with caution. The algebra appears formidably tedious if one should wish to check the results.

R68-13905 ASQC 824; 822
TOLERANCE REGIONS FOR A JOINT EXPONENTIAL DISTRIBUTION.
Lee J. Bain (University of Missouri, Rolla, Mo.).
IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 111–113. Research supported by AEC.
(A68-18422)

Consideration of the evaluation of the reliability of a system of components, when the components are assumed to follow a joint exponential distribution. The approach used is to develop tolerance regions for the joint exponential distribution or to estimate the probability content of the appropriate specification region. Author (IAA)

Review: This is a well-written mathematical paper concerned with the estimation of tolerance regions for a joint exponential distribution. The joint density function is assumed to be the product of k independent exponential density functions. The paper summarizes some mathematical results, drawing from sources which are not so well known, for the derivation of tolerance regions. Several cases are considered with respect to the shape of the tolerance regions. The shape should conform to that of the specification region when one does not want to be too conservative concerning the tolerance estimation procedure. This paper will be of interest to statisticians and to reliability analysts concerned with obtaining tolerance regions or with estimating the probability that the components of the system will meet a given specification, given that the joint exponential distribution is applicable. A possible application of these techniques is to estimating the probability that k independent variables $(x_l, ..., x_k)$ fall within a specification region S. If x_i is the life-length of the *ith* component of a system, then S can be considered to be the acceptable or required lives of the individual components.

R68-13909 ASQC 824; 844
REPLY TO COMMENTS ON "A CAUSAL REDEFINITION OF FAILURE RATE—THEOREMS, STRESS DEPENDENCE, AND APPLICATION TO DEVICES AND DISTRIBUTIONS."
Robert G. Stewart (Lockheed Palo Alto Research Lab., Palo Alto, Calif.).
IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 134, 135. 5 refs.

Hazard function is discussed in relation to failure rate; and it is noted that if hazard function is given the connotation of failure rate, then a rapidly increasing failure rate is attributed to the most reliable devices in a distribution or those that survive the longest. If any averaging is done of the hazard function over the test interval, it would be determined by the end of test singularity and would be heavily weighted by the best devices, with early failures contributing little. Hazard function is not considered to be constant in an exponential distribution whose devices all die in a finite time interval, while failure rate function does remain constant. It is stressed that the statistical and physical aspects of reliability are not independent of each other, and that very frequently statistical analyses are the only means of approaching reliability. M.W.R.

Review: This Letter to the Editor is in response to a review (see Ref. 1 in the Letter and R68-13582) of a former paper by the author (see Ref. 2 in the Letter and R67-13215). The comments in this Letter clearly do not stand alone and one must look at both Refs. 1 and 2 in the Letter in order to have a clear understanding of the original paper and the subsequent comments. The reviewer endorses the comments made in Ref. 1. The reply to these comments as given in this Letter is subject to misinterpretation and can be misleading. Some detailed comments are the following. (1) The sentence "Contrary to a widely held belief, the hazard function is not constant for an exponential distribution whose devices all die in a finite time interval" is logically inconsistent because if all devices fail in a finite time, the distribution of failure times cannot be exponential. (2) The statement "The major increase in the hazard function occurs near the end of the test.... If we ascribe the connotation of failure rate to the hazard function, then a rapidly increasing failure rate is attributed to the most reliable devices in the distribution..." is misleading. Near the ends of the lives of any elements, they are very likely to fail (by definition) apart from any considerations bearing on the previous length of life; therefore, the hazard rate at a time near the end of life will reflect that fact. (3) The statement "The figure of merit which is employed for part selection should be responsive to those early failures..." does not recognize the fact that a high hazard rate near time zero is most indicative of the presence of early failures. (4) F_{TR} in the text refers to "TRaditional failure rate" (as mentioned in the original text). It is called "the most likely estimate of the failure rate." Actually it is the maximum likelihood estimate for the *constant hazard* rate; therefore, the use of F_{TR} in the Weibull example is incorrect. The above negative comments are typical of those that can be made about the Letter. If the author had wished to define a new variable $x = l/t$, where t is the time to failure, he could have done so in a simple way. For example, consider the exponential distribution of t. The corresponding probability density function for x is $\lambda x^{-2} \exp(-\lambda/x)$. The lack of understanding of the notion of the hazard rate or hazard function is worth elaborating upon only because it may be widespread. If the random variable t is continuous (it may take on any value in an interval), it will have a probability density function p(t). The reliability is the integral of this density function from t to infinity, or the area under the right-hand tail of the density function curve. The hazard function is the density function divided by the reliability. It applies to this

continuous random variable. Thus the hazard rate is the rate of failure of the presently-living population.

R68-13910 ASQC 824; 433

THE EFFECT OF K-FACTORS ON THE UNCERTAINTY OF FAILURE-RATE PREDICTIONS.

David M. Brender

IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 135, 136. 1 ref.

(A68-18424)

Determination of the uncertainty involved when multiplying a failure rate by a k-factor (stress factor) to account for the effect of a more severe environment. Practical evidence of this uncertainty is supplied by the large deviations frequently encountered between predicted and measured results. The use of Bayesian ideas to measure this uncertainty is demonstrated. IAA

Review: Any good reliability analyst is already well aware of uncertainty in k-factors for failure rate adjustment in reliability predictions. This brief presentation, which is Bayesian oriented, illustrates mathematically the effect of the uncertainty on prediction results and notes that the effect always adds to the uncertainty. The points are well made and are well worth noting by all those who make or use reliability predictions. Unfortunately, in practice little information is usually available on the uncertainty of the k-factors; e.g., MIL-HBK-217A lists k-factors for various operating environments with nothing stated about their variability. If a prior distribution can be agreed upon, the procedures described in the paper are applicable. In some cases one may wish to specify an uncertainty to represent some degree of disbelief. Most predictions, however, will continue to be performed using constant k-factors. Generally speaking, the situations when uncertainty in k-factors potentially becomes most important are when the prediction results are to be used as absolute measures of reliability or are to be used as bases for comparing alternate designs which differ considerably in either composition, configuration, or application.

R68-13912 ASQC 824; 552

DEVICE FAILURES DURING EQUIPMENT LIFE FOR LOGNORMAL DISTRIBUTIONS.

William G. Ansley (Hewlett-Packard Co., Lab., Palo Alto, Calif.).

IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p 139, 140. 1 ref.

(A68-18426)

Presentation of a simple graph showing the total fraction of devices which will fail over any given time for lognormal failure distributions. The result is a function of the median life and the geometric dispersion. Author (IAA)

Review: This paper deals with one of the kinds of graphs that engineers draw for themselves from time to time to make certain calculations easier. The paper is marred by the following deficiency: Hazard rate and failure rate are confused inexcusably. By coincidence the author's method of getting the total fraction of failure is exactly right and not approximate as he states. Some careless terminology in the paper can cause considerable confusion but has been clarified by the author in a private communication. The terms "expected life" in the early part of the paper and "equipment life" in the latter part of the paper and the graph, mean simply "time". These terms have nothing to do with any statistic of the population but merely refer to the independent variable "time". The details of the derivation for the graph are a matter of personal taste; many will probably find a slightly different approach preferable.

R68-13913 ASQC 824

RAND Corp., Santa Monica, Calif.

RELIABILITY ASSESSMENT IN THE PRESENCE OF RELIABILITY GROWTH

A. J. Gross and M. Kamins Sep. 1967 65 p refs

(Contract F44620-67-C-0045; Proj. RAND)

(RM-5346-PR; AD-659773; N68-24206)

A methodology is presented for estimating current and future reliability of complex weapon systems that show reliability growth during their development and early operational phases. The study proposes four reliability growth models or patterns that can be fitted to actual data experience to determine the quantitative characteristics of the growth within relatively well-defined tolerances. This is achieved by defining appropriate parametric models and subsequently using maximum likelihood procedures to obtain estimates of the parameters. Comparison of the models shows that under the conditions set forth in this study, three are generally superior in their predictive and assessment characteristics to representative nonparametric methods and to an applicable Bayesian procedure. Author (TAB)

Review: Except for an appendix which presents the mathematical analysis of reliability growth models, this report is essentially the same as the paper covered by R68-13858. The review of the later paper applies to this report also.

83 DESIGN

R68-13864 ASQC 835

TERMINOLOGY AND CLASSIFICATIONS; THE RELIABILITY OF HYBRID SYSTEMS, MODULES, AND COMPONENTS; MICROELECTRONICS AND SYSTEMS EFFECTIVENESS.

S. M. Stuhlbarg (Raytheon Co., Missile Systems Div., Bedford, Mass.)., Joseph R. Frissora (Space and Tactical Systems Corp., Burlington, Mass.), and Thomas E. McDuffie (U. S. Naval Applied Science Lab., Brooklyn, N. Y.).

Electronic Communicator, vol. 2, Jan./Feb. 1968, p. 4, 6. 8 refs.

Statistical determination of reliability and use of redundancy to improve hybrid integrated and microelectronic circuitry are discussed, and mention is made for the need for a packaging technology that permits interconnection of the access to the active circuitry. Vendor interfaces and the role of the designer are considered; as are factors affecting reliability, failure mechanisms, and adaptable multifunction design. M.W.R.

Review: This entire issue of the *Electronic Communicator* is devoted to hybrid microelectronics. In the introduction are three papers which discuss reliability, namely the ones by Stuhlbarg, Frissora, and McDuffie. The first paper discusses the paradox which exists when the reliability is so high that it is difficult to prove by practical statistical methods. Then the advantages of redundancy which can be achieved with microelectronics are mentioned. These few paragraphs devoted to reliability are adequate as an introduction, but it will have no use as a reference. The second paper is devoted entirely to reliability. Some factors which affect circuit reliability when using hybrid components are mentioned (things such as environment are not stated explicitly). A few failure mechanisms are discussed; they are valuable information. While some indication is given of the number of millions of module hours both in orbit and on the ground, no mention is made of the number of failures experienced in those hours. No comparison is

made with integrated circuits. All in all the paper serves a useful purpose as a very brief general introduction to the reliability of these components. The author in a private communication has indicated that it was abstracted from a lecture, and that he can supply more complete information. The third paper is nominally concerned with systems effectiveness but actually deals with modules which can have several functions depending on how they are wired. An example is given both for a linear amplifier and for a digital block. The increase in reliability is presumed to come from the making of many modules which are the same and are then modified in the assembly process to serve various overall functions. These are akin to operational amplifiers which can be used similarly. The paper does contain useful information although it is not related to what is ordinarily considered systems effectiveness. In a private communication the author has stated that the paper was considerably shortened from his presentation, and that a document, soon to be released by his laboratory, is quite complete. It is entitled "Navy Systems Design Guidelines Manual, Microelectronics Applications."

R68-13877 ASQC 831; 824; 872

SYSTEM ENGINEERING FOR RELIABILITY AND EASE OF MAINTENANCE.

K. F. Rankin (Plessey Co., Ltd., Systems Development Div., Poole, Dorset, England).

(Institution of Electronic and Radio Engineers, Institution of Production Engineers, and Institution of Electrical Engineers, Joint Conference on the Integration of Design and Production in the Electronics Industry, Nottingham, England, July 10–13, 1967, Proceedings.) Radio and Electronic Engineer, vol. 35, Feb. 1968, p. 67–80. 10 refs.

(A68-21545)

Discussion of the lessons learned from several years of investigation into the performance of a large air traffic control (ATC) data processing system. To achieve the requirements of reliability and ease of maintenance, the time between faults must be made as long as possible, while the time required to clear a fault must be reduced to the minimum. The practice of building up some degree of system redundancy with standby equipment is also one that can be employed to ensure that the occurrence of a fault does not cause an appreciable loss of system facilities. The experimental ATC system, on which the original findings were based, illustrates the feasibility of designing a high standard of reliability into data-processing equipment. Extensive data on the performance of the system have since been analyzed and used to improve further the reliability factor. Author (IAA)

Review: System engineering does not overly concern itself with the details of the black boxes it assembles. This paper treats factors which affect the reliability and the ease of maintenance of a system. The reliability portion is concerned largely with repair time versus mean-time-to-failure of the components, and ease of maintenance is concerned with the three facets of (a) detecting the existence of a fault, (b) locating and clearing the fault, and (c) repairing the failed components. This paper gives a reasonable discussion of these three topics. It is also concerned with effective ways of recording the failure data so that worthwhile changes can be made to the system. The section involving redundancy contains some algebra which is difficult to follow, not because it is complicated but because the notation is not clearly defined and because the approximation—time for repair is much less than the mean-time-to-failure of each component—is always used, even when not apparent. Even the equations which are presumed to be exact suffer from this difficulty. The derivations are extremely abbreviated and thus it is difficult to tell whether the basic approach is correct. No references are given to a more detailed derivation. A table gives some of the failure experience, but the transistors and diodes are labeled by part number and thus difficult for us in this country (or perhaps anyone not familiar with this system) to interpret.

R68-13880 ASQC 838

ESTIMATING THE OPTIMUM POSITION FOR RESTORING ORGANS IN CASCADED REDUNDANT NETWORKS.

C. S. Repton (University of Birmingham, Dept. of Electronic and Electrical Engineering, Birmingham, England).

Microelectronics and Reliability, vol. 7, Feb. 1968, p. 1–10. 14 refs.

The design of redundant circuits using separate decision elements, or restoring organs, is discussed for the special case of cascaded networks. Methods of placing the restoring organs so as to achieve maximum effect are considered, and design procedures are developed which allow the design of redundant circuits giving maximum reliability for a stated cost, or circuits which have a given level of reliability for minimum cost. Author

Review: This is another one of the papers having to do with restoring devices used in redundant circuits in the way, for example, that majority voters are used. Many special and general cases have been investigated by several authors over a period of years, and it is difficult to say whether one article overlaps another or not since many of the references are quite scattered. The model which is hypothesized in this paper is not unreasonable, but its construction should be carefully studied before using the results. For example, if failure is likely to be due to a rare drastic increase in severity level of the environment, then this kind of redundancy will do little, if any, good since statistical independence of the failures is presumed. The mathematics was not entirely checked although it seems to be competent (except for the explanation of the notation: for example, P and F both seem to be used for probabilities without any clear explanation of which is which; another example of unexplained notation occurs on page 9 where C is said to be 0, 1, or 3 without any explanation of what C is—except that it is not the one being used elsewhere on that page). The article is intended for system designers, apparently, but it will be difficult for them to make use of the knowledge since the material is presented in a form for theoreticians.

R68-13891 ASQC 831; 882

MISSION RELIABILITY FOR PLANETARY SURVEYS.

A. H. Hevesh (Avco Corp., Wilmington, Mass.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p 516–521. 10 refs.

(A68-19529)

Discussion of the reliability of systems used for geological and geophysical space missions. It is shown that the unmanned system is more reliable than the manned system if the concern is merely with the likelihood of a single shutdown event taking place. But this measure of system merit is significant only for non-maintained systems which cannot be restored once they have failed. It is pointed out that, by using the availability measure as the index of comparison, the superiority of the manned system becomes more evident. IAA

Review: Anyone concerned with comparing the degree of success of an unmanned, non-maintained system with that of a manned, maintained system will be interested in this paper. The subject is discussed in a clear and straightforward manner, and the mathematics is such that it can be followed readily by anyone who understands fundamental probability. The paper serves the needs

of those who want a brief and easily-read overview of the subject, as well as those who wish to delve deeper, because the discussion is keyed to ten references which may be used to obtain further details. The paper makes it clear that the reliability needs of the two types of systems, unmanned and manned, are quite different. While the unmanned system tends to rely on minimal failure rates and redundant backups in critical systems, the manned system relies on the human crew supplied with sufficient maintenance tools and spare parts. The higher availability of the manned system is of course offset by the cost and payload weights of the life-support and crew-return requirements. The extension of mission goals as a result of the presence of the human crew is an important advantage of the manned system. These considerations must be kept in mind at the concept stage in spacecraft development, and this paper will be worthwhile reading for those concerned with this activity.

R68-13892 ASQC 831; 612; 844
RELIABILITY ANALYSIS OF SHIP SYSTEMS DURING CONTRACT DEFINITION.

John R. Lennon (Consultec, Inc., Washington, D. C.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 545–557. 1 ref.

Major problem areas facing the marine reliability analyst during contract definition are summarized; and two analytical techniques, GEM and a simulation model, are presented for quantifying ship system reliability. The Generalized Effectiveness Method (GEM) is preferred when sufficient input data are available because of its accuracy, speed, and conventionality. The GEM technique provides the reliability analyst with a set of user directions, a library of network or system descriptions, a formula library, and a processor. The formula library contains computer programs that are adaptable to many analytical configurations, and describes a system in a design oriented language. Drawback of GEM is that it requires the development of complex block diagrams to represent the system. The mathematical simulation model, based on Monte Carlo sampling techniques, offers the user many options. Failure criteria, the multi-mission aspect of a ship system, performance degradation, subsystem interactions, onboard repair, and operating cost reliability analysis are discussed. M.W.R.

Review: Complex systems such as ships which have multiple mission and on-board repair capabilities create special problems in reliability assessment. This paper provides a good orientation to reliability analysis of systems of this type. Whereas depth is sacrificed for breadth, the presentation is generally clear and informative. Both the experienced analyst and the novice can benefit from this paper. One exception to clarity is the attempt to distinguish between "mission reliability analysis" and "operating cost reliability analysis"; it is not clear precisely how they differ in role and procedures. There appears to be appropriate emphasis on other key factors such as failure criteria, multiple missions, performance degradation, interaction, on-board repairs and data. There is also an interesting discussion of the use of scenarios as a method for coping with the complexity of the system and operation in the analysis. The two analysis techniques, Generalized Effectiveness Methodology (GEM) and the simulation model, are not pursued in depth, but enough discussion is given to enable the reader to appreciate how they work and what they can do. A more detailed treatment of GEM is given in the paper covered by R68-12608.

R68-13900 ASQC 831
SPACECRAFT MISSION EFFECTIVENESS.

Abraham Leventhal (NASA, Goddard Space Flight Center, Greenbelt, Md.) and Charles E. Bloomquist (Planning Research Corp., Los Angeles, Calif.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 615–621. 6 refs.

Assessment of a methodology for evaluating spacecraft effectiveness both prior to launch and during the course of an individual mission. These evaluations are then related in a meaningful manner. The a priori and a posteriori evaluation of spacecraft effectiveness are mathematically combined into a single measure which is indicative of the accuracy of the a priori evaluation at any point in time and which, when combined with sound-engineering evaluation, can be used to improve both the accuracy of the prediction and the operational effectiveness of future spacecraft. The entire development is carried out in terms of the Orbiting Geophysical Observatory (OGO) project. IAA

Review: A case study is presented concerning the effectiveness of the Orbiting Geophysical Observatory spacecraft. The measure of effectiveness which is used is essentially the reliability and capability of the various modes of the spacecraft. Cost is not explicitly considered. This paper illustrates a maturing of reliability analysis. Several indications of this are the following. (a) The many possible system states are explicitly considered, as opposed to an analysis based on the simple dichotomy of "good" or "bad". (b) As spacecraft were successively launched, there was a feeding of experience back into the analysis approach. (c) The iterations of prediction and measurement yielded results which influenced the design and the operation of later spacecraft.

R68-13901 ASQC 830; 883
SUCCESS ASSURANCE FOR MANNED PLANETARY EXPLORATION.

Roy B. Carpenter (North American Rockwell Corp., Aerospace and Systems Group, Space Div., Downey, Calif.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 622–630. 5 refs.
(A68-19534)

Analysis of some of the problems facing reliability and maintainability engineers with respect to future manned space missions. The following problems are mentioned as examples of problems of primary concern: (1) identifying where maintenance actions will be required; (2) planning for the supporting payload; and (3) identifying the mission and crew-imposed restraints. IAA

Review: This paper will be of interest to reliability and maintainability engineers who are working on the design of spacecraft for manned planetary exploration. The concept described by the author is that of an optimum combination of man and machine working in harmony, one compensating for the potential inadequacies of the other. An important part of the planning is the identifying of the maintenance requirements, which is based on available reliability data. The maintenance time constraints are described as more restrictive than the actual reliability of the equipment, and the tolerance of systems to temporary malfunctions is a key factor in manned planetary mission success. The paper is a brief and clear discussion of these and related points, suitably illustrated with figures, charts, and tables. Five references are cited, pertaining to earlier publications by the author on this topic.

R68-13911 ASQC 838; 821

RELIABILITY PREDICTION FORMULAS FOR STANDBY REDUNDANT STRUCTURES.

Carl J. Benning (Texas Instruments, Inc., Dallas, Tex.)

IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 136, 137.

(A68-18425)

Development of the reliability prediction formula for standby redundant structures, and discussion of its application in predicting reliability. Structures involving N identical components, of which at least k ($k<N$) are required for system operation and N–k are in standby are considered. The result shows that the k out of N standby structure is more reliable than the on-line structure, providing switching is perfectly reliable. IAA

Review: This letter derives the formula for the reliability of a redundant system under the following conditions: (1) k units must operate for the system to be up, (2) $N \geq k$ units are available, (3) the hazard rate of non-operating units is zero, (4) k and only k units are operated, (5) the hazard rates of the operating units are all the same and constant with time, (6) failure events are statistically independent, and (7) switching is immediate and perfect; there is no repair. Formulas of this kind appear frequently in the literature, especially in some of the translations from the Russian, since they are fond of this kind of derivation. It is usually difficult for anyone (prospective authors, users, or reviewers) to locate them so that this possible duplication is helpful. It would be worthwhile for someone to attempt the task of making a handbook of Reliability formulas so that one need not reinvent the wheel whenever he needs a formula, but can look to see if it already exists. The mathematics in this paper was not completely checked but it appears to be quite competent.

84 METHODS OF RELIABILITY ANALYSIS

R68-13863 ASQC 844

IMPROVING BEARING RELIABILITY.

P. S. Given (SKF Industries, Inc., King of Prussia, Pa.).

Machine Design, Feb. 15, 1968, p. 192, 194, 196. 1 ref.

Lubrication evaluation, performance prediction, and use of antifretting coatings are discussed in terms of improving rolling bearing reliability. Studies have shown that both fatigue life and wear in a rolling contact are functions of the minimum thickness of the hydrodynamic oil film in the contact; and that when a full elastohydrodynamic film exists, there is no surface reaction and fatigue life may exceed rated life by a factor of two or more. An electrical conductivity method of measuring the asperity contacts of rolling bodies was developed to determine the degree of surface separation of elastohydrodynamic films; and it is shown that contacts through the lubricant film progressively reduce as the speed is increased for a fixed load, lubricant, and operating temperature. The prediction approach can be used during the initial design phase as well as a diagnostic tool to correct and explain field troubles. Bearing coatings tested and their capabilities and costs are tabulated. M.W.R.

Review: This summary deals largely with the effect that lubrication has on bearings (bearings which contain rolling elements) and gives some curves for helping to predict the adequacy of lubrication. The formulas and curves, however, need information which can be supplied only from extensive tests and are quite empirical. The chances are very good that some of the constants in the formulas will be different for different kinds of bearings, but the principles expressed by these formulas and the trends indicated will undoubtedly still hold. Skepticism and caution should accompany any use of probability of survival curves with fractions above 99% since the uncertainties become very great in this region. The paper will be helpful to designers who are not familiar with the way lubrication affects the life of bearings.

R68-13865 ASQC 844

National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va.

AN EMPIRICAL EQUATION RELATING FATIGUE LIMIT AND MEAN STRESS

I. E. Figge Washington, NASA, Apr. 1967 30 p refs

(NASA-TN-D-3883; N67-23286) CFSTI: HC$3.00/MF$0.65

An empirical relation was developed to predict the fatigue limit of axially loaded unnotched specimens as a function of mean stress. Both the ultimate tensile strength and the fatigue limit at zero mean stress are required in the basic equation. An ancillary equation was developed to represent the fatigue limit at zero mean stress as a function of the ultimate tensile strength. Comparisons demonstrating the improvement of the proposed relations over other relations are presented for five major material classes: bare aluminum, clad aluminum, low alloy steels, stainless steels and superalloys, and titanium alloys. The proposed method predicted that it was possible to obtain a fatigue limit equal to the ultimate strength of the material. Various materials tested at approximately the stress levels predicted by the method had not failed after 2.5×10^6 or more cycles. Author

Review: This paper is recommended for design engineers or other persons making stress analyses in materials subjected to fluctuating loads. The empirical relation proposed in this paper provides a good fit to observed data for five major material classes: bare aluminum, clad aluminum, low alloy steels, stainless steels and superalloys, and titanium alloys. Heretofore designers and analysts have commonly used the Gerber–Goodman or Soderberg relations for predicting the fatigue limit under fluctuating loads. Designers commonly use the Gerber relation when the mean stress is positive (a tensile stress) and consider the results to be on the conservative side. The Goodman relations are normally used when the mean stress is negative (in compression), the results not necessarily being conservative. To circumvent the problem of having to decide which relation should be used, the author has presented, for the five general classes of materials cited, an empirically-derived formula which may be used for either compressive or tensile mean stresses. Also, the results obtained when the mean stress is positive are more accurate than the Gerber relation and hence tends to prevent overdesign. It should be mentioned that in this region of positive mean stresses, the results obtained from the Goodman equations are not necessarily always conservative, a fact which some designers realize. Unfortunately, the author did not report on any possible findings for material classes other than those mentioned. Nevertheless, the five classes presented represent some of the more commonly used materials in flight vehicle design and, therefore, should be of benefit to persons working in these areas.

R68-13866 ASQC 844

Aeronautical Research Labs., Melbourne (Australia).

FATIGUE OF METALS—WHERE IT STANDS TODAY

J. Y. Mann Mar. 1966 42 p refs Presented at the Metal Treatment Div., Australian Inst. of Metals, Melbourne, 4 Nov. 1965

(ARL/SM-305; N67-35135) CFSTI: HC$3.00/MF$0.65

Current concepts and developments in fatigue testing equipment, standardization of tests, and the determination of realistic fatigue data are discussed and reference is made to basic research and environmental effects. Consideration is also given as to how fatigue failures can be reduced by engineering design and

metallurgical processing, and special reference is made to the problem of the design and treatment of welded joints. Author

Review: This paper is a review of the current concepts and developments in fatigue testing equipment, standardization of tests, and determination of realistic fatigue data. Since it is a review, most of the topics are treated in greater detail elsewhere. The author does an excellent job, however, of presenting the information in a clear, concise manner; therefore, the document is recommended as a first reference to gain an initial insight into the general problem area, particularly for the novice. The paper is well documented with literature references and graphical and tabular data. The author's major conclusion that the greatest improvement in fatigue performance is achieved through engineering design, rather than metallurgical processing, is worthy of attention; and design engineers should be aware of this fact. Fatigue is one of the most important failure modes of structural parts and so deserves much attention from designers.

R68-13869 ASQC 844

FAILURE BEHAVIOR OF COMPOSITE HYDROCARBON FUEL BINDER PROPELLANTS.

T. M. Jones and R. B. Kruse (Thiokol Chemical Corp., Structural Integrity Section, Huntsville, Ala.).

(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D. C., Feb. 1–3, 1965.) Journal of Spacecraft and Rockets, vol. 3, Feb. 1966, p. 265–267. 6 refs. Research supported by the Army.

(AIAA Paper 65-156; A66-21946)

Study of the mechanical failure of solid propellants, in order to determine failure prediction criteria. Since, for most propellants, the time and temperature dependencies of failure can be combined in a single temperature-reduced time variable, an attempt is made to construct a failure surface for constant strain rate tests in principal stress space. Experimental data are presented which suggest that such a surface inscribes a triangular prism in the negative principal stress octant, and is a dilatational plane in the positive principal stress octant. Attempts are also made to correlate a portion of the uniaxial failure boundary with various energy criteria. The path dependence of conserved energy is also discussed. IAA

Review: This article is an "Engineering Note" and, as such, it is written in a brief but editorially sound format for prompt publication. There are sufficient graphical illustrations to support the text, but a less knowledgeable reader will have to rely on the list of references for an understanding of the concepts of failure behavior in hydrocarbon fuels. The authors have related the text to two current failure problems—failure of solid propellant motors stored at low temperature and failure of small analog motors at higher strains than the larger prototype motors. This is a physics-of-failure type of paper. The mathematics of the paper was not checked in detail but appears to be competent. (There is a suspected printing error for an upper limit of integration in the equation for D-dot in the first column on p. 265).

R68-13870 ASQC 844

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

STUDYING CYCLIC STRENGTH OF METALS BY THE METHOD OF RECORDING FATIGUE DIAGRAMS

T. A. Lebedev, T. K. Marinets, and A. I. Yefremov 29 Apr. 1966 14 p refs Transl. into ENGLISH from Tr. Inst. Met. Akad. Nauk SSSR (Moscow), 1962 p 141–146

(FTD-TT-65-1402; TT-66-62429; AD-640287; N67-15309) CFSTI: HC$3.00/MF$0.65

Conclusions: By recording the fatigue diagram of samples tested under the effect of cyclic loads, an indirect representation can be obtained of when fatigue of metals appears and the formation of fatigue fracture does take place. It therefore appears advisable to carry out an investigation of fatigue strength of metals by the proposed method on a much wider circle of materials. TAB

Review: This is an unedited rough draft translation of an original Russian text. The paper is short and the subject matter is of current interest, but it is not recommended as a reference. The word order and sentence structure of the translation are awkward; furthermore, the details concerning experimental procedure and experimental results are too few to determine specimen geometry, load spectrum, or mode of failure. If one insists on reading the paper, access to the literature references would be necessary for full comprehension of the work.

R68-13871 ASQC 844; 782

Lockheed-Georgia Co., Marietta.

SONIC FATIGUE IN COMBINED ENVIRONMENT Technical Report, Apr. 1964–Dec. 1965

John R. Ballentine, Harry E. Plumblee, and Cecil W. Schneider Wright-Patterson AFB, Ohio, AF Flight Dyn. Lab. May 1966 164 p refs

(Contract AF 33(615)-1481)

(ER-8452; AFFDL-TR-66-7; AD-637506; N66-39475) CFSTI: HC $3.00/MF $0.65

Research on sonic fatigue in combined environment is described. Emphasis is placed on determining the effects of structural curvature, low-frequency vibratory loads, and heat, both singly and collectively, on sonic fatigue. The analytical and experimental investigation is presented in two major phases: (1) An investigation of simple structural panels to determine the effect of curvature and heat cycling schemes on dynamic response and fatigue. (2) An investigation to determine the effects of high-intensity sound, heat, and low-frequency vibratory loads on curved titanium-faced honeycomb sandwich panels. Author (TAB)

Review: This technical report presents the results of an extensive research effort to establish tolerance levels and design criteria for prevention of sonic fatigue. The study includes the effects of combined environments—acoustical noise, heat, and low frequency vibrations—and curvature on sonic fatigue. Various kinds of fatigue are very important failure mechanisms in aerospace vehicles. The mathematics will be difficult to follow for anyone who is not intimately familiar with the notation and formalism being used. It is also tedious, perhaps necessarily so, to follow the results as they are presented—since no clear broad picture of them is presented in advance. (These comments are not meant to denigrate the work but rather to measure the ease of its assimilation.) The mathematics appears to be competent, but was not checked in detail. The manuscript is well documented with more than 80 graphical illustrations and 21 references to the technical literature, but, because of its mathematical nature, it is not recommended for general reading. It would, however, be a useful reference for senior scientists or senior research engineers.

R68-13872 ASQC 844

National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

APPLICATION OF A DOUBLE LINEAR DAMAGE RULE TO CUMULATIVE FATIGUE

S. S. Manson, J. C. Freche, and C. R. Ensign 1966 47 p refs Presented at the Symp. on Crack Propagation, Atlantic City, N. J., 26 Jun.–1 Jul. 1966 Sponsored by the Am. Soc. for Testing and Materials

(NASA-TM-X-52226; N66-31229) CFSTI: HC$3.00/MF$0.65

The validity of a previously proposed method of predicting cumulative fatigue damage based upon the concept of a double linear damage rule is investigated. This method included simplified formulas for determining the crack initiation and propagation stages, and indicated that each of these stages could be represented by a linear damage rule. Data were obtained in two stress level tests with maraged 300 CVM, and SAE 4130 steels in rotating bending. Two strain level tests were conducted in axial reversed strain cycling with maraged 300 CVM steel. The investigation showed that in most cases the double linear damage rule when used in conjunction with originally proposed equations for determining crack initiation and propagation predicted fatigue life with greater or equal accuracy than the conventional linear damage rule. An alternate viewpoint of the double linear damage rule is suggested which may have value in the prediction of fatigue life under complex loading spectra. Author

Review: Anyone who has read a multitude of papers on the subject of cumulative fatigue realizes that the use of the linear damage rule as assumed in Miner's theory does not, in many cases, predict fatigue life with the accuracy desired. Miner's equation is still used, however, because of its simplicity and ease of application. The double linear damage rule described in this paper proposes that the accuracy of Miner's equation can be substantially improved if the process of fatigue failure is divided into two stages—crack initiation and crack propagation—and Miner's equation then applied separately to each stage. This suggests that linear damage occurs in the crack initiation stage. Subsequently, crack propagation progresses, again assuming linear damage until failure occurs. The authors have done an excellent job in presenting the concept, analytical applications, and test data to substantiate the concept. Although some discrepancies are found with respect to test validation of analytical predictions, the use of this concept substantially improves the accuracy of Miner's equation for predicting fatigue life under variable loading. An alternate method is also described to improve accuracy still further. The latter method departs slightly from the original hypothesis. This paper makes an excellent contribution to the field of cumulative fatigue study.

R68-13873 ASQC 844

THE EFFECT OF PARTIAL REPLACEMENT ON THE RELIABILITY OF A CLOSED GROUP OF ROLLING BEARINGS.

T. A. Harris, S. F. Aaronson, and R. Piante (SKF Industries, Inc., Engineering and Research Center, King of Prussia, Pa.).

(American Society of Lubrication Engineers, Annual Meeting, 20th, Pittsburgh, Pa., May 2–5, 1966, Paper.) *Lubrication Engineers,* Aug. 1966, p. 310–315. 5 refs.

A statistical technique is presented that develops a method to predict the effect on reliability of a group of rolling bearings when fractional parts of the group are periodically replaced by a prescribed preventive maintenance schedule. Data obtained indicate that only an ample bearing replacement rate at small fractional life intervals can be sufficient to reduce unscheduled machine down-time significantly. Because improved bearing steels, manufacturing methods, and lubrication techniques tend to increase rolling bearing fatigue life, reliability for required time in service is improving. As fatigue life is further increased, the failure-free life becomes sufficiently long to permit its use as a design criterion. It is concluded, therefore, that 100% reliability will eventually be ascribed to rolling bearing operation and that 100% replacement will be recommended at the termination of the no-failure life if this 100% reliability is to be maintained. M.W.R.

Review: There is a possibility that in some systems a random periodic replacement of a portion of a large group of bearings will improve reliability sufficiently to make such action economically feasible. An augmented Weibull distribution has been used to relate reliability and probability of failure in terms of the number of bearings being periodically replaced, the replacement interval, and the number of bearings in the group. The paper includes several interesting examples that illustrate the use of the relationships obtained. These relationships require that the group of bearings be similar with respect to rated life and also that they be applied under the same operating conditions. It appears from the data and illustrations that only when large replacements are made at short intervals does unscheduled down-time become significantly reduced. It also appears that the greatest difficulty is in determining when the technique is warranted. Consideration will have to be given to the cost of periodic replacement as opposed to the net cost of either replacing bearings only when failure occurs or completely during off-season periods. The paper is easy to read and follow with the exception of the development of the equations for reliability which is not sufficient to enable them to be completely checked.

R68-13874 ASQC 844

Royal Aircraft Establishment, Farnborough (England).

A METHOD OF FATIGUE LIFE PREDICTION USING DATA OBTAINED UNDER RANDOM LOADING CONDITIONS

W. T. Kirkby and P. R. Edwards Jan. 1966 46 p refs

(RAE-TR-66023; AD-642978; N67-17844) CFSTI: HC $3.00/MF $0.65

Preliminary tests were made to investigate a method of fatigue life prediction in which fatigue data obtained under a simple form of random loading are substituted for the data hitherto obtained under sinusoidal test conditions. The results of this work show a significant increase in the accuracy of prediction, but it is evident that further allowance for load interaction effects is necessary, if greater accuracy is to be obtained. Author (TAB)

Review: This paper appears to make an important contribution toward improving techniques now being used to predict fatigue life under varying load conditions. The concept presented basically consists of using Miner's equation for cumulative fatigue damage; the fatigue curves are based on RMS load values obtained from random-type loading rather than on constant amplitude loading. This concept has been logically developed, and may improve the accuracy of linear cumulative damage predictions. The basis for replacing the use of constant-amplitude fatigue curves centers mainly on studies that suggest that fatigue damage under random loading is not necessarily proportional to the load level being applied but rather is dependent on previous load-cycle history. This leads to the concept that the use of RMS load values from random-load fatigue tests will tend to adjust for the variations found in the life predicted by Miner's theory when used with constant-amplitude fatigue curves. The proposed method seems to improve accuracy, but there is some doubt as to whether consistency is also improved. This method poses some difficulty in the selection of a random load program with the proper load density distribution and in the complexity of the fatigue testing equipment needed. The subject is well treated here and deserves attention by those engaged in cumulative fatigue studies.

R68-13876 ASQC 844

ON THE PHYSICS OF PURPLE-PLAGUE FORMATION, AND THE OBSERVATION OF PURPLE PLAGUE IN ULTRASONICALLY-JOINED GOLD–ALUMINUM BONDS.

Gordon K. C. Chen (Collins Radio Co. of Canada, Ltd., Microelectronics Dept., Toronto, Ontario, Canada).

IEEE Transactions on Parts, Materials and Packaging, vol. PMP-3, Dec. 1967, p. 149–153. 21 refs.

By treating the gold wire aluminum thin film joint as a diffusion couple at low concentrations above dilute levels, bond

strength decrease resulted in increasing electrical resistance. From Arrhenius-type plots at 105°, 156°, and 203°C, the apparent activation energy for thermal annealing of ultrasonically film bonds was found to be 12.8 kcal/mole. The diffusion model is independent of the method by which the aluminum and gold are joined, and the unique slope of the plot suggests that thermal diffusion is the only mechanism causing change in the bond. Bond failures are directly linked to the progression of diffusion. The model suits the Au-on-Al bond structure because of the apparent disparity of diffusion rates; application of the model to other systems must consider factors such as superlattices. M.W.R.

Review: The underlying physical principle of the experiment described in this paper is that the bulk resistivity of an alloy increases as the solute concentration increases. Thus the total resistance of a series of aluminum strips interconnected by gold wires should increase as the aluminum from the strip diffuses into the gold wire contacts, increasing the concentration of aluminum (which is the solute) in the gold–aluminum alloy. The author has carried out aging experiments at three different temperatures on such aluminum–gold configurations and has deduced therefrom a reasonable activation energy for the diffusion of aluminum into gold. The author concludes that his experiment confirms the diffusion model of intermetallic compound formation between gold wires joined to aluminum films as described by workers at Autonetics (see R67-13359, R67-13368, and R67-13392) and others (see R67-12932 and R67-13360), although he states, in a subsequent private communication, that he believes that bond deterioration can be explained by the diffusion process alone, i.e., compound formation is not necessary to explain the observed failures. This is probably the significant message of the paper for reliability engineers; metallurgists, physical chemists or other specialists may find the details of the experiment worth pondering. The paper contains a reasonably complete bibliography on purple plague. Several editorial deficiencies should be mentioned:

1. In many of the equations the omission of brackets makes it impossible to distinguish between terms in the denominator and terms in the numerator. Equation 3 written as

$$c(x,t) = \alpha/\sqrt{\pi Dt}\,\exp(-x^2/4Dt),$$

means

$$c(x,t) = \frac{\alpha}{\sqrt{\pi Dt}}\exp(-x^2/4Dt).$$

In Equation 4 the denominator is missing altogether. It should be as follows:

$$\rho_a(T) = \rho' + K\frac{\alpha}{\sqrt{\pi Dt}}\exp(-x^2/4Dt).$$

Equations 9, 10, and others are similarly subject to misinterpretation for the same reason so that the reader must work out all the expressions himself to keep the numerator and denominator straight.

2. The three temperature points investigated are listed differently in different places—the abstract describes the three temperatures as 105°C, 156°C, and 203°C; the subscripts of various *a* factors describe the temperatures as 156, 203, and 256; in all the figures and in at least three places in the text the experimental temperatures are given as 156, 203 and 252. Presumably, by majority rule, the latter three temperatures are the correct ones. Nothing hinges on knowing the proper values unless one attempts to confirm the calculated activation energy.

3. The "Boltzmann constant, R" is listed on p. 152 in the paper as 1.987×10^3 kcal/mole °K; it should, of course, be called the gas constant and is 1.987×10^{-3} kcal/mole °K. The Boltzmann constant, k, has units of "per molecule" and is rarely given in calories.

R68-13881 ASQC 844

FAILURE ANALYSIS OF PLANAR TRANSISTORS USED IN THE UK3 SATELLITE PROGRAMME.

P. J. Holmes and I. C. Jennings (Ministry of Technology, Royal Aircraft Establishment, Farnborough, Hants., England).
Microelectronics and Reliability, vol. 7, Feb. 1968, p. 37–44. (A68-20749)

Account of the modes of failure of all the rejects from the 3922 npn and 925 pnp planar transistors used in building the prototypes and flight model of the UK 3 satellite. The results indicate that the screening criteria specified were very effective in eliminating certain types of fault, though others, especially potential bond failures and foreign inclusions, were not adequately screened. These can only be avoided by improved process control in manufacture combined with visual vigilance by operators at every stage of production. Author (IAA)

Review: Failure analysis falls somewhat in the category of God, mother, and country—everyone is for it in principle, but in practice these things sometimes suffer. This paper gives results wherein every failure, including incoming inspection failures, was analyzed and the results have been recorded. The work appears to have been done competently and reported well. The conclusions are reasonable from the data; unfortunately they are likely to be of little consolation to anyone. While the results pertain only to two particular transistor types made over three years ago, there are probably many of the same problems existing today. This paper can be of assistance to reliability engineers and others who are responsible for reliability and quality of hardware.

R68-13882 ASQC 844

RELIABILITY ENGINEERING.

M. R. P. Young (Texas Instruments Ltd., Bedford, England) and D. A. Peterman (Texas Instruments Inc., Dallas, Tex.).
Microelectronics and Reliability, vol. 7, Feb. 1968, p. 91–103. 16 refs.

Reliability engineering efforts during semiconductor device development are discussed, and the relationship between fabrication techniques and failure mechanisms is stressed. Current state of knowledge on semiconductor device reliability is reviewed; and reliability testing, data analyses of failures, and failure mechanisms are considered in detail. Test results are discussed and displayed graphically as log normal distributions which represent surface controlled parametric changes as well as contact failures. Developmental techniques that can be used to improve reliability are described. M.W.R.

Review: Even though the title is misleading (it should read: Reliability Engineering in Semiconductor Device Development"), the paper is remarkably practical in its outlook and is quite informative. The discussions involving statistics avoid getting tied up in details which sometimes plague other papers. It is interesting to compare this paper with another paper in the same issue ("Failure Analysis of Planar Transistors Used in the UK3 Satellite Programme," by Holmes and Jennings, p. 37–44). The problems being considered in the other paper are not the kinds of failure in general which are being designed against in this paper even though both kinds are important. One paper is written by a consumer and the other by a manufacturer; reading both is necessary to get a balanced viewpoint on problems with semiconductor devices. The paper can be of value to reliability engineers and semiconductor specialists, although similar material appears elsewhere from time to time.

R68-13886 ASQC 844; 821; 824

RELIABILITY GROWTH IN REAL LIFE.

Ernest O. Codier (General Electric Co., Defense Electronics Div., Aerospace Electronics Dept., Utica, N. Y.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968 p 458–469.
(A68-19526)

Discussion of monitoring, forecasting, and presentation methods of reliability prediction that work and are believable. It is shown that the Duane chart appears to be a powerful analytical tool for constructing reliable estimates of the current status and rate of reliability growth. It is pointed out that the amount of evidence which has been accumulated and interpreted in the Duane model is at this point completely convincing that this particular model is an effective representation of the real world. The two resulting corollaries are: (1) failure rate at any level of assembly is a constant only under some rather special conditions; and (2) failure rate at any level of assembly may be reduced to arbitrarily low values by continual effort. Data taken from Duane's original report show his model continuing to operate at 6 million test hours. IAA

Review: This is a well-written and interesting paper concerning the subject of reliability growth analyses. A parametric reliability growth model form based on an exponential function is proposed by the author. The reasons for using this model are (1) considerable validation based on data, (2) physical significance of constants, and (3) a simple computational procedure for evaluating constants from data. The technique proposed by the author seems to be good for point estimates; however, some further statistical considerations of these estimates would be a good subject for additional study. This need does not detract from the value of the paper, as many references suffer under this standard. Further application of these concepts will aid in model validation and suggest avenues for further theoretical work. This paper is good reading for those interested in the subject of reliability growth modeling techniques. There have been many papers concerning this subject; however, only a few are referenced in this paper. For additional references see, for example, R63-10895, R66-12476, R66-12663, R66-12772, R67-12981, R67-13060, R67-13101, and R67-13103.

R68-13893 ASQC 844
RELIABILITY OF MICROELECTRONIC CIRCUIT CONNECTIONS.
R. Bryant, M. H. Bester (North American Rockwell Corp., Autonetics Div., Anaheim, Calif.), and J. McCormick (Air Force Systems Command, Research and Technology Div., Rome Air Development Center, Griffiss AFB, N. Y.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 558–566. 5 refs.
(A68-19531)

Description of a test program used to establish failure rates of lap-soldered and parallel-gap-welded microelectronic circuit connections. The program described involves subjecting approximately 50,000 normal, marginal, and submarginal connections to both usage conditions and accelerated conditions. The manner in which the samples were prepared for testing is discussed, and numerous conclusions are presented. IAA

Review: Since this is a summary paper adapted from a final project report, it is not possible to evaluate any of the methods used in the test or analysis. The results, however, do appear both reasonable and useful; the discussions of failure modes and mechanisms should be especially helpful. The original report is referenced for those who wish to go into the subject in greater detail.

R68-13897 ASQC 844
SEMICONDUCTOR DEVICE LIFE AND SYSTEM REMOVAL RATES.
D. S. Peck (Bell Telephone Laboratories, Allentown, Pa.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 593–601. 6 refs.

A pattern of active device removals is indicated from data on electronic systems that (1) question the assumption of a constant failure rate or removal rate and (2) require that system results be described in terms of elapsed time of system operation unless a constant removal rate is demonstrated for the component in question. Transistor removal rate pattern with time is similar to the device failure rate pattern determined from accelerated testing data, although a causal relationship with time is not obvious because many of the transistor failures during early system life appear to be due to factors external to the transistor, that is, related to system testing procedures. Device failure rates are discussed, and it is shown how an estimate of expected transistor removal rates in a system can be derived from device reliability data and the system removal rate history. M.W.R.

Review: The failure behavior of semiconductor devices is a topic of much concern and of much controversy. This largely philosophic paper ably presents a discussion of transistor removal rates (as opposed to transistor failures). The behavior over time, where enough failures occur to make this presentation meaningful, is important since there may be many factors causing the removal rate to change with time. In this kind of analysis and discussion it is sometimes difficult to distinguish between the observed facts and the underlying model to be hypothesized for explaining those facts. It is interesting that extensive servicing is presumed to cause much trouble, from which it takes the system quite a while to recover. This paper is important from the standpoint of practical reliability engineering and maintenance.

R68-13898 ASQC 841
SOLID LOGIC TECHNOLOGY COMPUTER CIRCUITS—BILLION HOUR RELIABILITY DATA.
Edward F. Platz (International Business Machines Corp., Components Div., East Fishkill Facility, Hopewell Junction, N. Y.).
In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 602–606.

Reliability of Solid Logic Technology (SLT) microminiature hybrid high performance and low cost computer circuits is considered as is the Failure Analysis Information Retrieval (FAIR) program being conducted on the IBM system/360 that uses SLT circuits as logic building blocks. Circuits of the 30 nanosecond family, the logic work horse in five models of the 360 line, are considered; and by noting the distribution of actual component usage, the average module consists of one transistor chip, two dual diode chips, and three resistors. The number of failures in a given observation period as well as the population and power-on-hour occurrence during the same interval are combined to demonstrate a module failure rate of less than 0.003% per 1000 hours; with systems power-on-hours ranging from less than 2000 to more than 12,000. Principal failure

modes and mechanisms for SLT, determined by the FAIR program, are (1) ball joint, 68%; (2) lands, mechanical damage, 16%; (3) surface defects, 7%; and (4) miscellaneous, 9%. The SLT resistor has a mean time to failure in excess of 12 billion hours.
M.W.R.

Review: A very brief description is given of the Failure Analysis Information Retrieval (FAIR) program being conducted on the IBM System/360. The description is too brief to be of much use to anyone who might wish to implement a similar program. The functions which are outlined are simply those which one would reasonably expect. A difficult task in any such program is the obtaining of adequate and accurate data from field operation. On this point, more detail in the paper would have been desirable. For example, mention is made of a Product Analysis Incident Report card, but the specific information which is recorded on the card is not given. A picture of the front and back of the card appears on page 606 in the paper but it is so small that it serves only to show that information on failed components is recorded on a specially-printed IBM punch card; no detail can be read from it. There are three sentences in the paper in which the author's meaning is not clear. These are the following: (1) "These extrapolations were performed prior to seeing more than sketches of the proposed product." (2) "The definition of failure used in the FAIR program is a true, practical reliability analysis in terms of the measure of impact on IBM systems." (3) "As we progress to large scale integration, the smaller numbers of specialized functions produced may impact the experience factor otherwise to be gained with large production." In summary, this paper, which is addressed to a topic of importance to reliability engineers, is sufficiently lacking in detail and clarity so that it is of little use for its intended purpose.

R68-13906 ASQC 844; 824

RELATION OF A PHYSICAL PROCESS TO THE RELIABILITY OF ELECTRONIC COMPONENTS.

Clarence F. Kooi (Lockheed Palo Alto Research Laboratories, Palo Alto, Calif.).

IEEE Transactions on Reliability, vol. R-16, Dec. 1967, p. 113–116. 6 refs. Research supported by Lockheed Independent Research Funds and NSF.

An ensemble of electronic components having a random variation of some parameter, such as surface contamination, is considered. A physical process is postulated which leads to a change in one of the operating characteristics of the device. When this operating characteristic attains a value outside an acceptable range, the device is considered to have failed. The failure rate is calculated directly from the time behavior of the physical process and compared, for illustration, to the Weibull failure law. The parameters of the Weibull law are then related to the parameters of the physical process and the distribution of starting parameters.
Author

Review: Trying to find a suitable model, which is based on some simple elementary concepts, for failure of electronic components is an activity of the theoretically inclined engineers which too seldom finds its way into print. Not all of the ones appearing in print will go down in history as the turning point of the ages. In fact, what is probably needed is a place where these theories can be aired without having to become archival documents since many of them are definitely not suited for that category. This paper is one of those interesting attempts; the physics is handled reasonably well, but the mathematics is abominable. There are two blatant errors, described as follows. (1) The normalizing factor associated with Eq. 9 is incorrect. The author's method of normalizing results in an indeterminate form; the proper normalizing factor comes from Eq. 5 and the correct probability density function (pdf) is $pdf(x) = 2h^2x \exp(-h^2x^2) = (1/x^*)(x/x^*) \exp[-(x/x^*)^2/2]$ where x^* is the mode of x. (2) The formula for the number of failed components is in error and the associated explanations are in error including the one about not being able to integrate from 0 to N_c for the reliability. The correct expression for the failure function, F, is $\exp[-(N_c f(t)/N_0^*)^2/2]$ where N_0^* is the mode of N_o, N_o is the maximum limiting number of degraded particles, and f(t) is the author's $(1-e^{-2\alpha t})$. The author's graphs and comparisons with the Weibull distribution are thus all wrong. He states that the Gaussian distribution cannot be integrated in closed form. This is true if he means to say that the integral of the Gaussian distribution is not one of the elementary functions, viz., one that you learn in high school mathematics. But the integral of the Gaussian distribution is well-known and well-tabulated. It lacks a suitable name, but is very closely related to the error function. The minor discussion on whether the Gaussian distribution can represent reality or not (because it goes below zero) is not an important one since what goes on in the far tails of any distribution is rarely known. It is worthwhile to go through the author's analysis for the general functions rather than the specific ones. The probability of failure is then $F(n_c,t) = CDF_R[n_c/f(t)]$ where $CDF_R(x)$ is the Cumulative Distribution Function (of x) from the Right and $f(t) = n(t)/n(\infty)$ where n(t) is the number of degraded particles, and n_c is the critical number of degraded particles to cause failure and is a constant independent of N_o (by the author's assumption). It is thus easier to see how the function of time and the CDF_R produce the indicated behavior. The paper will be of no concern to the practicing design engineer, but can add to the pool of theoretical ideas if this review is used in combination with the paper.

R68-13914 ASQC 844

Radio Corp. of America, Camden, N. J.

MODELING OF INTEGRATED CIRCUIT EFFECTIVENESS (MICE) Final Technical Report

Bernard F. Tiger and David I. Troxel Griffiss AFB, N. Y. RADC

Jul. 1967 111 p refs

(Contract AF 30(602)-3526)

(RADC-TR-67-267; AD-658199; N68-24205)

The Stress Survival Matrix Test (SSMT) and Physical Effects Analysis (PEA) program was conducted on a type of monolithic silicon integrated circuit from two vendors. The purposes of the program were to identify the basic reliability characteristics of integrated circuits and determine an approach to reliability prediction having greater practicality and validity than the currently used techniques. The development of the SSMT, analysis of the resulting data, and the PEA results are described. It is shown that the reliability of suitably used integrated circuits is not primarily a function of usage factors such as temperature, power, or shock. It is more directly dependent on (1) screening effectiveness, (2) the failure mechanisms which exist in field use units and (3) the life distributions and environmental susceptibilities of the units which have these failure mechanisms. These results suggest that failure rate decreases with time as the deviate units (i.e., those containing failure mechanisms) drop out of the population of survivors. The problem of assuring suitable usage is discussed, and an appropriate prediction approach, incorporating the pertinent factors that affect reliability, is identified.
Author (TAB)

Review: This is the report upon which the paper covered by R68-13838 is based. They share much of the printed text in common. This main report contains much more of the data description and less of the final evaluation comments than does the later paper. The review of the later paper applies to this report also.

R68-13889 ASQC 851; 770; 782

EFFECTS OF SUSTAINED TEMPERATURE CYCLING ON PARTS.

Jack Q. Reynolds (Collins Radio Co., Cedar Rapids, Iowa).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 486–493.

(A68-19528)

Study of the effect of sustained temperature cycling on electronic-part failure rates. The typical MIL-STD-781A thermal environment is described, and the type of parts and components found most susceptible to degradation or failure is discussed. An evaluation of extensive part-level sustained temperature cycling is made. Corrective action taken on certain part types is reviewed, and recommendations for industry and government action are made. IAA

Review: Choice of proper environment under which to test parts of systems in order to simulate or anticipate the problems which will arise in use is still more of an art than a science. This paper is an endeavor to further that art by discussing the effects of repeated temperature cycling on parts for several hundred cycles. The author is naturally concerned about the poor response of parts to these tests since he is a system manufacturer. This kind of cycling can be justified technically, if not financially, on the basis that many of the things that happen in test could happen in service for this or other reasons, i.e., the several hundred temperature cycles will expose weaknesses in the part, usually of a mechanical nature. The fact that appreciable degradation can take place is of proper concern, since, as the author points out, such tests are often used for burn-in. This is an important subject, but how far up on anyone's list of priorities it will be is hard to determine. Reliability engineers should be aware of the problem.

R68-13894 ASQC 851; 770

RELIABILITY TESTING OF F-111A AVIONICS SYSTEMS.

E. S. Minner and H. A. Romero (General Dynamics, Research and Engineering Dept., Fort Worth, Tex.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 567–575.

Reliability test requirements, subcontractor reliability program elements, and test criteria and environment are discussed for the F-111A avionics equipment. Major subcontractors were given comprehensive reliability program specifications, which included the mean time between failure (MTBF) requirement as a parameter for each equipment. These MTBF's were considerably higher than for the preceding generation of functionally similar avionics; and equipment reliability tests were designed at the 90% confidence level. Rationale employed in the test design is discussed, and some test results are included. Equipment burn-in is considered imperative in preparing equipment for reliability testing, and burn-in periods exceeding more than 100 hours were not uncommon in the F-111A program. M.W.R.

Review: This paper provides a case-study description of reliability demonstration of high-reliability equipment and will serve as useful documentation of further experience in this activity. Sufficient test specimens were available in this application to permit a reasonably straightforward approach; fixed duration (time-truncated) tests were employed in a conventional manner. The description is relatively brief but adequate for the experienced reliability specialist to understand the procedures and appreciate the problems. Some interesting comments are included about discovering the necessity of burn-in during the program for preconditioning the equipment for reliability testing. Whereas burn-in was not initially a requirement, the burn-in duration established by experience in the program "...became a requirement on all like equipment subsequently delivered under production contracts." Some good illustrations of reliability growth with measured MTBF figures are also included. One wonders whether the present difficulties with the F-111 are in spite of this high avionics reliability.

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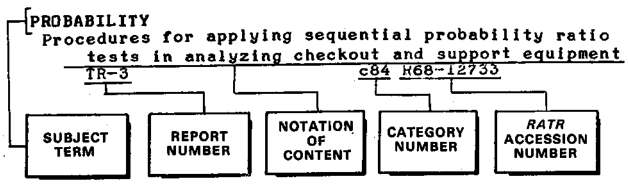

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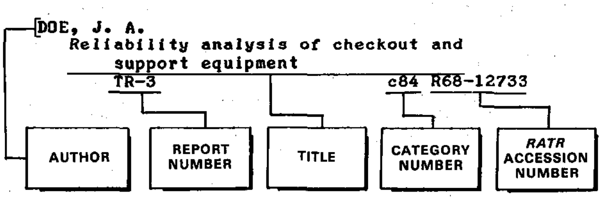

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Reliability Abstracts and Technical Reviews

AUGUST 1968

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R68-13915—R68-13968

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Reliability Abstracts and Technical Reviews

The first section of *RATR* contains bibliographic citations, abstracts, and reviews. The items (each identified by an *RATR* accession number) are arranged in subject categories based on the first two digits of the codes developed by the American Society for Quality Control. The complete listing of these ASQC codes appears on the inside back cover. Examples of citations of reports, journal articles, and conference papers are shown below. The principal subject field of the item (and therefore the category in which the item appears in the journal) is indicated by the first ASQC code number; related subject fields are indicated by additional code numbers. The appearance of a *TAB, STAR,* or *IAA* accession number indicates that the item has been announced in, respectively, *Technical Abstract Bulletin, Scientific and Technical Aerospace Reports,* or *International Aerospace Abstracts.*

The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

		ASQC CODES
RATR ACCESSION NUMBER	R68-12733 ASQC 844; 413	CORPORATE SOURCE
TITLE	General Equipment Company, Banville, Calif.	
	RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT	PUBLICATION DATE
AUTHOR	John A. Doe 23 Sep. 1966 27 p refs	
CONTRACT OR GRANT	(Contract NAS15-13411)	*TAB* AND *STAR* ACCESSION NUMBERS
REPORT NUMBER	(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65	SALES AGENCY AND PRICE

RATR ACCESSION NUMBER	R68-12739 ASQC 814	ASQC CODE
TITLE	**SEMICONDUCTOR RELIABILITY**	
	Joseph A. Smith (Eastern University, Arlington, Penn.)	AUTHOR AND AFFILIATION
JOURNAL REFERENCE	*Electric Journal,* vol. 8, Apr. 1966, p 478–492.	
	(A68-12569)	*IAA* ACCESSION NUMBER

RATR ACCESSION NUMBER	R68-12765 ASQC 773; 221; 823	ASQC CODES
TITLE	**TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES**	
	Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)	AUTHORS AND AFFILIATIONS
CONFERENCE OR SYMPOSIUM REFERENCE	*Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p*	
	Available from Assoc. of Reliability Eng., New York: $1.00	AVAILABILITY AND PRICE
IAA ACCESSION NUMBER	(A68-12407)	

OLUME 8 NUMBER 8

Reliability Abstracts and Technical Reviews

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81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13945 ASQC 813

National Aeronautics and Space Administration. Manned Spacecraft Center, Houston, Tex.

APOLLO SPACECRAFT RELIABILITY PROGRAM CONTROL—AN IMPORTANT ASPECT IN MAINTAINING A BALANCED RELIABILITY PROGRAM

J. H. Levine [1967] 21 p

(NASA-TM-X-60662; N68-11527) CFSTI: HC$3.00/MF$0.65

The paper outlines reliability program control methods relating to reliability task derivation, organizational reliability responsibilities, reliability milestones, reliability organization manning, and the concept of closed-loop management control systems for task implementation. Methods and techniques are discussed with particular attention to the Apollo spacecraft reliability program. Typical problems encountered in the Apollo spacecraft reliability program are briefly discussed. Author

Review: This paper, including six tables which are presented at the end, constitutes a reasonably detailed description of R & D reliability programs. It serves in part as an example of the implementation of the tasks described in NASA Reliability Publication NPC 250-1. Consequently, it will be of interest to those having responsibility for reliability programs on other complex R & D efforts. Prominent features of the paper are emphasis on (1) the need for task and milestone identification and (2) the need for management control systems.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13916 ASQC 824

EXPONENTIAL AND WEIBULL APPROXIMATIONS FOR CHAIN STRUCTURES.

Martin Messinger and Martin Shooman (Polytechnic Institute of Brooklyn, Electrical Engineering Dept., Brooklyn, N. Y.).

In: Annals of Assurance Sciences; Proceedings of the Annual Symposium on Reliability, Boston, Mass., Jan. 16–18, 1968. Symposium sponsored by the Institute of Electrical and Electronics Engineers, the Institute of Environmental Sciences, the Society for Nondestructive Testing, and the American Society for Quality Control. New York, IEEE, Inc., 1968, p. 494–508. 4 refs. Research supported by the Joint Services Electronics Program (U.S. Army, U.S. Navy, U.S. Force).

(Contract AF 49(638)-1402)

An exponential failure model applied to multicomponent systems reliability analysis is considered successful because the majority of such systems have series reliability and their component life testing is not usually complete enough to provide hazard rates much different from the initial value used by the model. Previously obtained results are generalized to a Weibull system reliability function which represents the asymptotic behavior of chain structures, and emphasis is placed on obtaining insight into errors involved in using the exponential or Weibull distribution as a system reliability model and determining how these errors depend upon the actual component hazards. Application of such approximations requires that only the initial behavior of the component hazard be precisely known along with the general shape of the hazard distribution. The asymptotic Weibull behavior for chain structures and of mean time to failure for these structures is demonstrated. The asymptotic Weibull behavior, and particularly the asymptotic exponential behavior, should be viewed in reliability theory as related to the central limit theorem of probability theory. M.W.R.

Review: This is a theoretical paper which attempts to generalize the limit theorem which states that under appropriate conditions and as the number of elements in the system becomes very large, the failure behavior of the system is exponential. The generalization consists of expanding the theorem to show under what conditions a Weibull distribution can be the result of the limiting process. The theorem as proved is unduly limited. The hazard rate can have less sedate properties and still converge to the Weibull formula in the limit. Furthermore, it is even easier to make a much more general observation, of which the earlier theorems are special cases. One of the difficulties for the uninitiated in reviewing this kind of theorem is that rarely is the theorem proved in a direct, straightforward form, but rather the proof involves a great amount of "Going around Robinhood's barn", sufficiently so that the heart of the process is obscured (whether unintentionally or not). The general observation is as follows: Let $R(N,t)$ and $H(N,t) \equiv -\ln R(N,t)$ denote respectively, the reliability and cumulative hazard function at time t for a system of N elements which are logically in series. If $H(N,t)$ can be expressed as $H_0(N,t) + H_1(N,t)$ where $\lim_{t\to 0}(H_1/H_0) = 0$ and where H_0, H_1, H are positive and monotonically increasing for both N and t, then $\lim_{t\to 0}(H_0/H) = 1$. This mathematical shorthand can be expanded to show engineers just what is implied by it in a practical sense. (1) Pick an $\epsilon > 0$ (ϵ may be as small as desired—

from step 3). (2) H_1 is restricted as follows: Let there be a $t_{max}(\epsilon)$ such that if $0 < t < t_{max}(\epsilon)$, then $0 < H_1(N,t)/H_0(N,t) < \epsilon$. (3) $H_0(N,t) < -1n\ R(N,t) \equiv H(N,t) < (1+\epsilon)\ H_0(N,t)$, $0 < t < t_{max}(\epsilon)$; i.e., $H = H_0$ within a relative accuracy of ϵ. (4) N can be adjusted (usually upward) so that $H_0(N,t_{max})$ has a reasonable value, e.g., let $H_0(N,t_{max})$ be constant, i.e., independent of ϵ. The functions H, H_0, and H_1 need only be sufficiently well-behaved that the operations in the observation are defined. (If H_0 is continuous at t=0, that is sufficiently restrictive.) Most derivations have caused the ratio in #2 to go to zero by indirect and obscure means; the observation above comes directly to the heart of the matter. It also shows that the function H_0 can be selected quite arbitrarily and shows what the properties of H_1 must be for that H_0. Two examples (akin to the text) will illustrate this point and show that the authors' restrictions are unduly severe (both assume the usual statistical independence).

Example 1.

(The exponential limit). Let $H_0(N,t) = N\lambda_0 t$ and

$$H_1 = \sum_{1}^{N} a_i t^{b_i}.$$

Then #2 gives

$$0 < \frac{1}{N} \sum_{1}^{N} \left(\frac{a_i}{\lambda_0}\right) t^{b_i - 1} < \epsilon.$$

From this, to have $b_i > 1$ (for all i) will be sufficient. It should be noted that $h_1(t) \propto t^{(b_i-1)-1}$ where $b_i - 1 > 0$. This is less restrictive than the text.

Example 2.

(The Weibull limit). Let

$$H_0(N,t) = \frac{N}{\alpha} t^{\beta};$$

$\beta > 0$ for $H_0(N,t)$ to be continuous at $t = 0$. Let H_1 be as in Example 1. It is easily shown that if $b_i > \beta$ for all i, the restriction in Step 2 above is satisfied. The same treatment as in Example 1 will show that this is a more lenient condition than in the paper.

The reason, of course, that the authors find that only the initial value of the hazard rate is important in their approximations is that they have indirectly forced time to go to zero. The derivation above in the review shows that (a) there is nothing magic about any of the limiting distributions which have been proposed here or in the literature, (b) any distribution can be used as a limiting distribution, and (c) the restrictions which the actual distributions must meet can be derived easily (easily in principle, that is, although it may be tedious in practice). In some of the figures in the text, viz., Table I and Figs. 5, 6 it is not obvious from the figures themselves that these are special cases. It is also not obvious what, in fact, is being done, viz., to work with the equation which shows just how short the time must be: error = 5000t. At the risk of repetition, the uninitiated should be warned that the kinds of derivations indulged in by the paper and this review hold only when the time is made very short, however circuitously this fact may be brought in. When the time is made very short, the reliability is likely to be very high unless the number of elements is increased heavily; so the number of elements is usually made correspondingly very large. The authors' method of calculating bounds on the error caused by one of these approximations may occasionally have utility for the practicing engineer; although this kind of work is of most value to the theoretician since the engineer cannot treat time as cavalierly as can the theoretician.

R68-13924 ASQC 824

RELIABILITY PHYSICS MODELS.

Martin L. Shooman (Brooklyn Polytechnic Institute, Dept. of Electrical Engineering, Brooklyn, N. Y.).

(Probabilistic Reliability: An Engineering Approach.) IEEE Transactions on Reliability, vol. R-17, Mar. 1968, p. 14–20.

(Contract AF 49(638)-1402)

(A68-27557)

Description of reliability failure models based on logical hypotheses as to how objects fail. It is noted that the generalized stress-strength model prevalent in current literature is perhaps the closest that analysts have come to a general physical model. To obtain a failure-density function and associated hazard function, a certain probability distribution for the part strength and a particular amplitude distribution and frequency-of-occurrence distribution for the part stress must be assumed. If a normal strength distribution and Poisson distributed-stress-occurrence times with normally distributed amplitudes are assumed, then this leads to an exponential failure-density function and a constant hazard. Such a model is probably best suited for situations in which the part generally lasts a long time and only seems to fail when, on occasion, a large stress occurs. In many situations the failure of parts seems to fit a different pattern. The part is operated at nearly a constant stress level; however, the part strength gradually deteriorates with time. As time goes on, the rate of deterioration should increase sharply as wear-out is reached, and cause an increase in hazard. A probabilistic model which fits this hypothesis is a constantly applied stress and a Rayleigh-distributed part strength. The parameter of the Rayleigh distribution is allowed to increase in an exponential fashion with time, thus producing the strength-deterioration effect. Basically the failure rate turns out to depend on the square of the applied stress; however, if the strength deterioration rate is allowed to be a function of the input stress, other behaviors are predicted. It is shown how time acceleration factors are a simple consequence of the model. IAA

Review: The subject of models for failure is one that needs to be explored much more thoroughly in electronics than it has been, and this paper is one of the beginnings in that direction. It is an exploratory paper rather than a definitive one, and must be read with that in mind in order to be appreciated. One minor difficulty is that the author occasionally assumes a particular kind of distribution and says it will not matter, but then one is not sure how much of the result depends on that particular assumption. If, in fact, it were independent of the assumption, it might have been wise not to assume any particular parametric form for the distribution. For example, in connection with the Rayleigh model, the hazard rate is a function of the square of the stress; the reader than has to go back and follow the derivation in detail to find that the reason the hazard is the square of the stress follows directly from the Rayleigh distribution. If the author, after showing a special case such as this, would show a more general case, one would be able to visualize more easily the relationship between the original assumptions and the final answer for hazard rate. The derivation involving the Poisson behavior is somewhat labored: if λt is in fact the mean number of stresses in the particular interval, then of course $p_f \times \lambda t$ is the mean number of stresses which produce failure in that interval (where p_f is the probability that a stress will be a failure-causing stress)—and all the author's intermediate steps are not needed. These comments should not be interpreted as being derogatory about the paper; those who are interested in failure models will find this discussion of value.

R68-13926 ASQC 823; 844; 851

APPLICATION OF CUMULATIVE DEGRADATION MODEL TO ACCELERATION LIFE TEST.

Hiroshi Shiomi (Ministry of International Trade and Industry, Electrotechnical Laboratory, Electronic Device Div., Reliability Research Group, Tokyo, Japan).

IEEE Transactions on Reliability, vol. R-17, Mar. 1968, p. 27–33. 10 refs.
(A68-27559)

Derivation from the reaction theory of a general degradation model, which includes conventional acceleration tests such as fixed, progressive, and step-stress experiments, under the assumption of linear degradation accumulation. The application of this model to an acceleration test is discussed. According to the reaction theory, degradation of the characteristic parameter μ is connected to the reaction rate K and time t by a linear transformation function $f(\mu) = Kt$. The total degradation is determined by the linear accumulation of the $K_i t_i$ product such as $f(\mu_n) = \sum^n K_i t_i$. This relationship is also expressed as a generalized Miner's equation $\sum^n (t_i/L_i) = 1$, in which t_i and L_i are the actual stressing time and the expected life, respectively, under the i-th stress condition, and $\sum^n t_i$ is the life expectancy of the component under successive stress conditions from $i = 1$ to n. The validity of this linear accumulation assumption is investigated for various stress-application paths. IAA

Review: This paper is very difficult to read for three reasons: (a) the author is not writing in his native tongue, (b) there is needless inclusion of irrelevant material, and (c) the ideas do not flow reasonably from one step to another. Examples of these difficulties are the following. (1) The derivations which are included under "Reaction Theory and Cumulative Degradation Model" are irrelevant to the theory; in fact, some are incorrect. If the time behavior of a parameter of interest is monotonic, there is always a transformation of the scale of that parameter such that the transformed parameter plotted against time yields a straight line through the origin (though the slope is not unique). (2) The linear theory *of cumulative damage can be hypothesized completely* independently of any reaction rate theory, and this paper would have been improved if that had been done. (3) Many of the examples, such as Figure 2, are not clear. (4) There is no mention of randomness in some of the important parameters. For example, life (even at constant stress) is a random variable, so that one would be surprised if the sum of the cumulative damage always came out to be the mean value. (5) The discussion on the shortcomings of the conventional step-stress method is not clear. (6) The discussion of acceleration factors appears confused, especially the acceleration factor related to hazard rate, since it seems to be comparing hazard rates at the same time rather than hazard rates for the same system state. (7) Contrary to the conclusions, cumulative degradation is not a fundamental principle of accelerated tests. Contrary to the introduction, step and progressive stressing do not require linear cumulative damage for their interpretation. While it would be possible for a knowledgeable person to make sense out of this paper, the effort would be largely the reader's. Thus this paper is not recommended, at least for tutorial purposes. The expert could figure it out given enough time, but he is already familiar with the material.

R68-13928 ASQC 824; 831

National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

ESTIMATING RELIABILITY OF COMPLEX SYSTEMS

Robert H. Ailor 9 Jun. 1967 78 p refs
(NASA-TM-X-53592; N67-29427) CFSTI: HC$3.00/MF$0.65

The analysis of simple systems is discussed whereby the system reliability equation can be determined by a relatively easy application of the fundamental probability theorems. For complex systems, two methods are presented. First, a canonical expansion scheme technique is used when the system has a relatively few number of components or the component probabilities of failure are small. If the number of components in a system is rather large and the above conditions do not hold, another method is presented to obtain the complete system reliability equation which depends primarily on defining pertinent output events for the system. The reliability functions for the components that make up a system are discussed and finally, a limited discussion is provided on implementing, controlling, and testing the solution in regard to reliability. Author

Review: The topics included in this technical memorandum constitute only a limited part of those which would come under the heading of "Estimating Reliability of Complex Systems". They have been presented elsewhere in various handbooks, manuals, textbooks, and other sources. This memorandum is thus tutorial; it is neither broad in scope, nor does it present anything new. The material which is presented is well-written from the standpoints of engineering, mathematics and common sense. Despite this, it is difficult to see any justification for the preparation of this technical memorandum. It is strictly for the novice to reliability prediction, and he will need to supplement it with other material from textbooks and handbooks. Hence he might as well rely entirely on those primary sources of information.

R68-13930 ASQC 824; 831

ON FINDING A NEARLY MINIMAL SET OF FAULT DETECTION TESTS FOR COMBINATIONAL LOGIC NETS.

D. B. Armstrong (Bell Telephone Laboratories, Inc., Murray Hill, N. J.).

IEEE Transactions on Electronic Computers, vol. EC-15, Feb. 1966, p. 66–73. 6 refs.
(A66-25804)

A procedure is described for finding, by shortcut methods, a near-minimal set of tests for detecting all single faults in a combinational logic net. The procedure should prove useful for nets which are too large to be treated by more exact methods. The set of tests so found also appears useful for diagnosing (i.e., locating) faults. The class of faults considered is that which causes connections to be stuck at logical one or logical zero. The nets considered may include AND, OR, NAND, NOR, and NOT gates. The bases of the procedure are the "path sensitizing" concept, and reduction of a net to its "equivalent normal form," abbreviated enf. It is shown that if a set of tests can be found which detects an appropriate subset of faults in the enf, this set will detect all faults in the original net. The enf also provides a vehicle for systematically finding the most desirable tests, namely those which each detect many faults in the net. The procedure is illustrated in detail by an example. Author (IAA)

Review: The algorithm presented in this paper is useful and easy to apply. The author's method of description-by-application is effective. This is a valuable and very readable paper. In too many papers of this kind, mathematical "nicety" seems to preclude clarity of expression. This is definitely not true for this paper. There are very few exceptions—for example at the bottom of page 69, 247→1, 47→2, etc. is needlessly confusing. 247→U, 47→V, etc. would have been better. The paper is also well organized. Relegating a proof (along with other less vital material) to the appendix adds to the readability.

R68-13933 ASQC 824; 433; 512; 838

BAYESIAN CONFIDENCE LIMITS FOR RELIABILITY OF REDUNDANT SYSTEMS WHEN TESTS ARE TERMINATED AT FIRST FAILURE.

M. D. Springer (General Motors Corp., AC Electronics, Santa Barbara, Calif.) and W. E. Thompson (General Research Corp., Santa Barbara, Calif.).
Technometrics, vol. 10, Feb. 1968, p. 29–36. 17 refs.

Exact Bayesian confidence limits are derived for the reliability of a redundant system of exponential subsystems, when subsystem tests are terminated at first failure. The application is conceived for the treatment of a redundant system having extremely high reliability, and allows a monomial family of prior density functions which is conjugate when tests are terminated at first failure. The posterior probability density function of system reliability is derived using the Mellin integral transform. The inversion is accomplished by the method of residues. From the density function the distribution function is obtained which yields confidence limits on reliability numerical inversion. Author

Review: The paper achieves the goal of its title. The authors do not discuss the interpretation of Bayesian confidence intervals but provide references thereto. Prospective users of the paper are warned to be sure that they know what the intervals say and that this is what they require. As a tie-in with previous work, note that this paper is the redundant-system analog of previous Springer–Thompson work (*IEEE Transactions on Reliability,* vol. R-16, p. 86–89; see R68-13581) and a correct answer to the problem considered previously and incorrectly by Briggs and Yarnell (*Microelectronics and Reliability,* vol. 4, pp. 235–240; see R67-13013).

R68-13934 ASQC 824; 512

COMPARISON OF TWO METHODS OF OBTAINING APPROXIMATE CONFIDENCE INTERVALS FOR SYSTEM RELIABILITY.

J. M. Myhre (Claremont Men's College, Calif.) and Sam C. Saunders (Boeing Scientific Research Lab., Seattle, Wash.).
Technometrics, vol. 10, Feb. 1968, p. 37–49. 7 refs.

Some specific comparisons are made between the use of the asymptotic Chi-square distribution of the likelihood ratio and the asymptotic normality of the maximum likelihood estimates to obtain confidence interval for reliabilities of arbitrary systems when only failure data on the components is known. In all the comparisons made, using moderate samples and systems of average complexity, the asymptotic Chi-square appears to give much more accurate confidence intervals. Although the asymptotic Chi-square method requires more computation for most systems than does the method based on asymptotic normality, these examples indicate the Chi-square method would yield superior results in most practical instances. Author

Review: This is a mathematical paper which makes a further contribution to the theory pertaining to the estimation of system reliability on the basis of failure data on components. This is an important problem in reliability estimation, which has received a considerable amount of attention from the theorists. In the context of the present paper, an earlier paper by the authors (see R67-13031) presented an extension of the results in the report covered by R65-12235. Those papers were concerned with a likelihood ratio method of obtaining approximate confidence intervals for series, parallel, and series-parallel systems. An alternate method based on a special case of the U-statistic was proposed in the paper covered by R63-10894. The present work is concerned with making comparisons between these two methods. The connections with previous work are well indicated and referenced in the paper. The work is clearly and concisely presented, and this paper represents a worthwhile contribution to the theory of reliability estimation. As such, it will be of interest to those who are concerned with the advancing of this theory, but not of practical interest to reliability engineers.

R68-13935 ASQC 824

STATISTICAL ESTIMATION PROCEDURES FOR THE "BURN-IN" PROCESS.

Richard E. Barlow (University of California, Berkeley), Albert Madansky (Market Planning Corp.), Frank Proschan (Boeing Scientific Research Labs., Seattle, Wash.), and Ernest M. Scheuer (The RAND Corp., Santa Monica, Calif.).
Technometrics, vol. 10, Feb. 1968, p. 51–62. 11 refs.
(Contract NASr-21(11))

Upper confidence bounds for failure rates at the end of a burn-in process are derived for truncated sampling and censored sampling modes, and the maximum likelihood estimator (MLE) of the failure rate function is derived for each of the modes. The MLE was obtained under the assumption of a decreasing failure rate, while the confidence bound assumed that the failure rate at the time burn-in ends was no greater than the failure rate throughout the testing period. A listing is included of the computer program that was developed for calculating a lower confidence limit for the parameter of the exponential distribution based on a truncated sample; and some examples using small sample size and small failure times illustrate results for both the truncated and censored data. M.W.R.

Review: This paper is the same as the original report which was covered by R67-12982.

R68-13943 ASQC 821

Joint Publications Research Service, Washington, D. C.

ON CALCULATING THE RELIABILITY OF TELEMECHANICAL DEVICES

K. G. Mityushkin and I. V. Prangishvili *In its* 22d All-Union Sci. Session Devoted to Radio Day. Sect. on Telemech. 18 Aug. 1966 p.102–108
(N66-36678) CFSTI: $3.00

The interconnection of various elements in telemechanical devices is considered the structural basis for the calculation of reliability. Coefficients of importance of elements are mentioned as being important for accurate characterization of reliability. It is noted that calculation of these importance coefficients emphasizes the fact that increasing the number of elements does not always decrease system reliability. Device reliability is defined in terms of performance, and the coefficients of importance are used in predicting device performance. M.W.R.

Review: This paper makes the usual assumptions of statistical independence and constant hazard rate, but weighs the failure probability of each element according to its importance or value in the system. Therefore, Reliability turns into the probability that the system will be doing everything you want it to do; and partial failures are accounted for. The algebra and the language are a little difficult to follow and some extraneous material on Information is introduced. There is little need for design engineers to wade through this paper since similar results would be available in the English-language literature.

R68-13949 ASQC 823; 615; 851

Massachusetts Inst. of Tech., Cambridge. Operations Research Center.

THE OPTIMAL BURN-IN TESTING OF REPAIRABLE EQUIPMENT

John Michael Cozzolino, Jr. Oct. 1966 134 p refs
(Contract Nonr-1841(87))
(TR-23; AD-642105; N67-17158) CFSTI: HC$3.00/MF$0.65

The infant mortality effect observed in the statistical treatment of reliability denotes a decreasing with time of the conditional probability of failure of a device which exhibits it. This widely

present effect may be utilized to improve the reliability by means of burn-in testing which seeks to discriminate between high and low quality units by accumulating operating experience upon all units. Burn-in testing is applicable to both unrepairable and repairable devices. The latter case is more difficult since the state of a failed and repaired unit usually depends upon the entire past history of the unit and upon the nature of the repair process. A general burn-in test problem for repairable devices is formulated based upon the explicit modeling of the repair process. The case of unrepairable devices is treated as a special case. Considering a particular conjugate form of the repair rule the burn-in test optimization is formulated as a sequential decision problem and the solution is discussed in terms of dynamic programming. An adaptive reformulation which allows a parameter of the failure process to be considered unknown is also given. Specific models of decreasing failure rate processes, based upon the population heterogeneity cause of decreasing failure rate, are given. Author (TAB)

Review: This is a theoretical paper and appears to be competent (although not all of the mathematics was checked). It provides a framework in which more-applied theorists can try out some models for reliability and repair and eventually produce something that the design engineer can use. In its present form the theory is too abstract for most design engineers; in fact they would have to study the paper for several days to be able to understand it, and even then their mathematical tools might be inadequate. One practical limitation on the theory is that it presumes that the environmental severity (severity of usage) is the same during burn-in as in field use (true acceleration would be allowed). But a burn-in where the conditions are adjusted so that weak units are treated more severely than the good units has advantages for burn-in (this is not to say the paper should have considered this case, but merely to point out that it does not). All in all this thesis can provide much good ammunition for engineering research for some time to come.

R68-13952 ASQC 824

Joint Publications Research Service, Washington, D. C.

THE LIFE OF A SYSTEM UNDER NONHOMOGENEOUS OPERATING CONDITIONS

O. V. Viskov *In its* Tech. Cybernetics, No. 6, 1966 14 Feb. 1967 p 144–147 refs

(N67-22413) CFSTI: HC$3.00/MF$0.65

A model is proposed for calculation of the reliability of a system taking into account the nonhomogeneous nature of use of the system. The Laplace–Stiltjes transformation of the time distribution of trouble-free operation of the system is calculated. Author

Review: This paper is rather difficult to follow unless one is quite familiar with the technique since the notation is strange and the translation is not fluent. The paper "solves" the indicated problem in terms of Laplace transforms. Obviously for many situations the resulting expression will not be tractable. The problem being considered is one wherein the system has a particular failure distribution while operating, a different one while not operating, and they are statistically independent. The results will be of concern only to the theorist. Someone may wish to evaluate the expression and plot curves for the use of engineers, although if the distribution functions are at all complicated it is likely that simulation will be used in solving the problem anyway.

R68-13953 ASQC 824; 851

Joint Publications Research Service, Washington, D. C.

DETERMINATION OF THE LIMITING LOAD WHEN CONDUCTING ACCELERATED TESTS

L. Ya. Peshes and M. D. Stepanova *In its* Tech. Cybernetics, No. 6, 1966 14 Feb. 1967 p 136–143 refs

(N67-22412) CFSTI: HC$3.00/MF$0.65

The principle of determination of the forced condition (limiting load) is proposed for conducting tests for reliability in the shortest times based on the general laws of expenditure of resources of the capacity to do work using products of various types. The algorithm for finding the limiting load is presented. Author

Review: This paper is difficult to decipher, at least because of the awkwardly translated language, and at most because of being poorly written in the first place. The following is the gist of the paper. First of all prepare an empirical cumulative damage curve, by plotting the time of the i^{th} failure against the cumulative fraction failed (the first point on the curve is the origin). Connect these points with straight line segments. Prepare such a curve for each of the stresses to be used in the step-stress test. Then the change in the cumulative probability function is taken as the measure of damage during any step and is presumed to be transferable to any other stress. Thus one merely cumulates the fraction failed at each step (as calculated from the above time versus fraction failed curves). When the cumulative damage is greater than unity (i.e., all of the samples are presumed to have failed according to the empirical cumulative failure curves), the step-stress should be stopped even though not all the samples have failed because it is presumed that the failure mode will change. Evidence is presented to support this conclusion. The paper needs to be discussed on two points: (1) the concept of cumulative damage being promulgated and (2) the concept of maximum legitimate stress. It is interesting to note that this concept of cumulative damage was presented, May 1968, in a paper by Leonard G. Johnson at the Twenty-Second Annual Technical Conference of the ASQC in Philadelphia (see p. 133–140 in the Transactions of that conference). This concept of cumulative damage is attractive on its face; but contains at least one extremely restrictive implicit assumption, viz., elements which are weak for high stresses are also weak for low stresses (this may often not be the case). The concept appears attractive because obviously it is true for any particular sample, i.e., they are being cumulatively destroyed. Therefore, this concept of cumulative damage should be empirically substantiated before being used, regardless of whether its source is the American or Russian literature. The second concept, that of the limiting stress, has some inconsistencies. The main one is that its value will depend very much on the empirical cumulative failure curve that has been generated, since the more samples there are the longer will be the time before the cumulative failure curve reaches unity. (What the author effectively does is to plot a confidence interval on either side of this line and proceed in an awkward fashion from there, but with no real change in the nature of the assumption.) Therefore, the contribution of this paper is to introduce a new concept of cumulative damage (some two years ahead of the American reference, although the American author may have earlier references to his idea). The concept has the advantage of tractability, if the curves are available for its use (this will very rarely be so). But it should be compared with other theories of cumulative damage to see if the answers are appreciably different. If so, then some physical basis should be used to make the choice between the concepts.

R68-13959 ASQC 824; 433

RELIABILITY STATEMENTS UNDER UNCERTAINTY.

Warren G. Briggs (Harbridge House, Inc., Boston, Mass.).

The Logistics Review, vol. 3 Jan./Feb. 1967 p. 11–19. 12 refs.

Component reliability is defined and the uncertainty of the failure rate is considered in terms of subjective distributions and Bayesian analysis. It is shown that if the failure rate of a conditional Poisson distribution has a Gamma distribution, the resulting

unconditional distribution of failures is negative binomial. A computation form for this unconditional distribution of failures is given and some numerical examples are included. Illustrative values of negative binomial probabilities are tabulated. M.W.R.

Review: Bayesian analysis of the Poisson model, in which the prior distribution of the failure rate is of the Gamma form is considered in this paper. Results are cited showing that the posterior distribution is also of the Gamma form, and that the resulting unconditional distribution of failures is negative binomial. A computation form for the negative binomial is given, together with some numerical examples. The paper does not claim to be a presentation of new material, and the sources of the results which are cited are adequately referenced. The paper, together with the references, will serve as useful tutorial material for those who are interested in the elements of Bayesian analysis as applied to simple reliability problems involving the Poisson distribution of failures.

R68-13960 ASQC 824; 872; 882

RELIABILITY OF A COMPLEX SYSTEM WITH TWO TYPES OF SUBSYSTEMS.

H. C. Jain (Defence Science Laboratory, Delhi, India).

The Logistics Review, vol. 3, Jan./Feb. 1967, p. 21–37. 5 refs.

Complex system behavior is considered that operates at reduced efficiency upon failure of one component (L_2) and completely breaks down upon the failure of another component (L_1). Failure and repair times for both these components follow exponential distributions. If L_1 fails while L_2 is being repaired, then the repair of L_1 takes precedence. The repair of L_2 is resumed later at the point where it was preempted. Both types of repairs are considered, and explicit solutions are derived using K-Erlang and exponential repair time distributions. Steady state solutions are derived by a corollary of Abel's theorem, and numerical examples are included. M.W.R.

Review: This paper is essentially an extension of the work reported in the paper covered by R64-11432, which was concerned with the behavior of a complex system having two classes of components or subsystems such that a failure in the first class causes a reduction in efficiency, whereas a failure in the second class causes complete system breakdown. Two different repair disciplines for the more critical subsystem are considered in this paper. Thus the term "reliability" as it appears in the title of this paper is interpreted in a rather general sense, and the connotation would more generally be given the name "availability." Reliability inputs are needed, of course, as are those concerned with repair. These considerations are becoming of greater interest with the advent of in-flight repair and reuseable systems. The paper is primarily mathematical, being concerned mainly with the derivations of the availability equations. However, the resulting equations are suitable for practical application, and numerical examples are given in the paper. Failures are assumed to follow the Poisson distribution, and repair times either the exponential or the K-Erlang distribution.

R68-13962 ASQC 824; 814

REPAIR VERSUS REPLACEMENT OF FAILED COMPONENTS.

W. R. Abbott (Lockheed Missiles and Space Co., Sunnyvale, Calif.).

Journal of Industrial Engineering, vol. 18, Jan. 1967, p. 21–23. 1 ref.

A model was developed to determine whether failed components should be repaired or replaced in the case of unmanned space systems where the primary consideration is the reliability reduction caused by the repair process. The criterion to be used is that of making the repair–replacement policy decision giving the largest cost effectiveness among feasible alternatives. Operation sequence of the system is defined, and the model is developed in detail. It is concluded that the decision to repair cannot be made on statistical grounds alone; and that, in the case under study, intelligent material review board action provides the most satisfactory approach for determining repair policy except for standardized cases which can be defined procedurally in advance. M.W.R.

Review: A cost-effectiveness approach is used as the basis for making the repair versus replacement decision, and a straightforward and relatively simple model is developed. The conclusion is then drawn that the decision cannot be made on statistical grounds alone, that is, that the model will not be of much help in the making of the decision. It is suggested that technical judgment in the form of intelligent action by the material review board provides a more satisfactory approach. This conclusion, which is a surprisingly candid one to be found in an applied mathematics paper, receives very little development. However, perhaps little is needed since the conclusion is realistic and consistent with the practical use which has been reported for many probabilistic models, particularly those designed for application to spacecraft systems.

R68-13966 ASQC 824; 433; 844

General Electric Co., Philadelphia, Pa.

ON BAYES' THEOREM AND ITS APPLICATION TO RELIABILITY EVALUATION

W. T. Weir 27 Apr. 1967 228 p refs Presented at the 3d Sem. on Bayes Theorem, 27 Apr. 1967

(Rept.-67SD213; N68-86487)

Nine seminar papers and a general introduction are presented on Bayesian methods for reliability analysis in the context of long-lived space systems. Bayesian analysis of multilevel contingency tables is reported, including a computer routine for inserting prior knowledge into a four-level table. A reliability oriented experiment in Bayesian statistics is described, as is a Bayesian approach to the estimation of availability. Other presentations deal with Bayesian confidence limits for determining the reliability of structures, use of decision statistics and the Bayes' theorem in formula selection, and implementation of Bayesian techniques at an industrial department concerned with reentry systems. Psychological research was performed on the use of Bayes' theorem as a model for human information processing, and a Monte Carlo approach is taken to reliability statements based on attribute data. Extending the use of Bayesian concepts is discussed in terms of the relationship between statistics and decision making, differing judgments as to what is important in the original work of Bayes, and differences between reliability as a design tool and as a management information system. M.W.R.

Review: A cross-section of Bayesian topics is presented in these ten papers from a seminar. The various papers contain a range of styles, mathematical elegance, viewpoints, and commodities used for illustrations. Although this was the third such seminar, the papers contain material which would be useful to those newly interested in the subject. For example, some appendix material presents the most basic notions in a simple manner. Thus, this is a useful single document for those interested in Bayesian Methods in reliability analysis. The General Electric Company is to be commended for sponsoring this service to the reliability community.

R68-13967 ASQC 824; 551; 872

Marine Engineering Lab., Annapolis, Md.

NONPARAMETRIC RELIABILITY AND MAINTAINABILITY SPECIFICATION FOR MECHANICAL SYSTEMS

Joseph I. Schwartz Dec. 1966 14 p ref
(TM-457/66; AD-643556; N68-86486)

A distribution-free method is presented for estimating reliability and maintainability probabilities of mechanical systems from operational tests. Because it is based on nonparametric statistics, the method provides conservative estimates that can be used in ship machinery specifications until more definitive data are obtained. The presented requirements can be used to establish a data bank into which data can be stored and distributions can be generated to define specific reliability and maintainability probabilities. M.W.R.

Review: This very short paper shows why the Navy chose a nonparametric test and what that test is. A simulation showed that the estimates of reliability, made by using the nonparametric method, were conservative when done with data taken from a known population (compared with results using the distribution of the known population). This finding is in agreement with generally-accepted conclusions. The formula which is given in an appendix, and the tables therefrom, may be of value to others in a similar position. It should be pointed out, however, that extrapolation is not possible with this method.

83 DESIGN

R68-13919 ASQC 831; 823
Illinois Univ., Urbana. Coordinated Science Lab.
COMMUNICATION NETWORKS WITH SPECIFIED SURVIVABILITY
David Eugene Butler Jul. 1967 40 p
(Contract DA-28-043-AMC-00073(E))
(R-359; AD-65651; N68-26716)

The paper considers the problem of the survivability of communication networks from the point of view of graph theory. Stations are represented by nodes of a graph and communication links between stations are represented by edges of a graph. The strength of a graph is defined with respect to nodes only, edges only, and both nodes and edges. Two methods of constructing graphs with specified strength are derived. Planar graphs are studied and a bound on their strength is found. Methods of finding the strength of an arbitrary graph are given. Author (TAB)

Review: This paper deals with a specialized kind of reliability, namely the ability of a communications station to communicate with other surviving stations when some lines and/or stations in the system have been destroyed. The model which is being analyzed should be carefully considered by anyone attempting to apply the results. For example, success is the presence of a channel with no regard to the loading capacity of that channel; stations and lines are considered either existent or nonexistent, i.e., none can be in a condition where partial transmission is possible. Some of these constraints are implied by the description of the model rather than being stated explicitly. The mathematical results are neatly summarized at the end, so that one need not be a mathematician in order to use them. (The mathematics was not entirely checked but appears to be quite competent.) In general, this is a good mathematical paper.

R68-13927 ASQC 838; 844
A COMPREHENSIVE RELIABILITY ANALYSIS OF REDUNDANT SYSTEMS.
Robert S. Pringle (Douglas Aiarcraft Co., Inc., Missile and Space Systems Div., Effectiveness Engineering Dept., Santa Monica, Calif.) and Philip M. Gresho (North American Aviation, Inc., Atomics International Div., Canoga Park, Calif.).
Journal of Spacecraft and Rockets, vol. 4, May 1967, p. 631–638. 8 refs.
(Contract AT(11-1)-GEN-8)
(A67-26828)

Analysis and discussion of the general effect of redundancy on system reliability. Three types of redundancy are described—active redundancy, standby redundancy, and active-standby redundancy—and equations are developed for each type of redundancy. The most significant contribution is the development of a Poisson-binomial probability distribution function (PDF) which applies to active-standby redundancy and is the general case of the Poisson and binomial PDFs. Special attention is given to the most general case (active-standby redundancy with start and switching—i.e., a modified Poisson-binomial PDF). The modified Poisson-binomial is applicable to systems where (1) the operating units have a constant failure rate characteristic of the operating mode, (2) the standby units have a different failure rate (also constant) characteristic of the standby mode, (3) all units are subject to failure when started, and (4) the standby units are also subject to failure when switched into the system. A rapid and accurate approximation technique for analyzing active-standby redundancy is also presented. Author (IAA)

Review: A useful contribution on the subject of structuring reliability prediction equations for complex redundant configurations is made in this paper. The paper concentrates on the derivation of the general redundancy equation. This is a permanent reference item for those interested in the fine points of reliability modeling and analysis. Although the fact is not mentioned in the paper, this equation would be useful as the reliability prediction equation for computerized approaches to redundancy allocation problems, such as those based on the dynamic programming principle.

R68-13929 ASQC 831; 612
Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
RELIABILITY MATH MODELING USING THE DIGITAL COMPUTER
Paul O. Chelson 15 Apr. 1967 25 p ref
(Contract NAS7-100)
(NASA-CR-84790; JPL-TR-32-1089; N67-28378)

A computer program is presented to calculate probability of system success from an arbitrary reliability block diagram utilizing the IBM 1620. It uses an algorithm that was developed using the probability tree method of calculating system success. The mechanics of the program are such that during execution it is possible to vary the probability of success as well as the arrangement of the blocks in the diagram to determine which combination has the greatest effect on the total reliability of the system. Author

Review: The reliability literature includes many items concerned with using digital computers for analyzing reliability models. However, in many of these it is difficult to reconstruct exactly what is being described or to obtain a specific description of the program. This will not be the case with this report. It is well written and well illustrated, and is self-contained, including a listing of the program. The particular analysis method used is a logic model patterned after the tree-diagram approach. The program is not particularly complex, but it is not restricted to series-parallel situations and it does allow for the multi-function type of reliability block diagram in which the same item may appear in the diagram for several functions. To the uninitiated, it should be pointed out that the framework of the model is logically implied by the computer program. The user expresses his system in terms required by that model, so that the analysis can be done easily.

R68-13931 ASQC 831
Naval Material Command, Washington, D. C.
NAVY SYSTEMS PERFORMANCE EFFECTIVENESS MANUAL
May 1967 58 p
(NAVMAT-P3941; AD-660413; N68-80718)

Techniques for the implementation of a Systems Performance Effectiveness (SPE) program are presented for use with Navy systems in fleet use. Factors and criteria for SPE are discussed, as are methods for technical communications and analysis. In regard to the latter a Generalized Effectiveness Methodology (GEM) is detailed, as is a design disclosure standard life cycle adaptation flow chart. Problems in SPE that are discussed include mission analysis, figure of merit formulation, degraded performance, modeling, and data quality. The relation of SPE techniques to the Research, Development, Test, and Evaluation (RDT&E) planning and acquisition process is detailed and various SPE models and their application are presented. M.W.R.

Review: Reliability considerations are key topics in this system effectiveness document. An overview is given of the Navy concept and approaches to system performance effectiveness. The concept makes sense and its implementation will serve to put reliability and related activity in its proper perspective. Although its title describes it as a manual, this report summarizes rather than going into detail. References are given on most of the principal topics cited. An exception, however, is the computerized analysis procedure called "Generalized Effectiveness Methodology" (GEM), for which no published reference is given. This report is apparently the Navy counterpart of the earlier Air Force WSEIAC Report (see R65-12200). It is thus a permanent reference item for those persons with interest in Naval reliability and system effectiveness. A minor nuisance in this document is that some of the block flow diagrams lose their legibility because of the extent to which they are reduced. In a private communication a Naval spokesman has indicated that the manual is being completely revised and will be republished as NAVMAT P3941-A, and that a GEM document will be announced soon by DDC.

R68-13936 ASQC 832
MINIMIZING HUMAN ERRORS.
Charles E. Cornell.
Space/Aeronautics, vol. 49, Mar. 1968, p. 72–81.
(A68-23935)

Analysis of the causes and remedies of human errors with respect to work involving spacecraft manufacturing. The four major causes of human error which are discussed include failure to follow procedures, incorrect diagnosis of particular situations, misinterpretation of communications, and insufficient attention or caution. The problem associated with quantifying human error is also discussed. IAA

Review: One often hears or reads remarks to the effect that the human element is an important source of unreliability in military and aerospace systems. Motivational campaigns such as Zero Defects represent one attempt to cope with this problem. The author of this paper takes the position that the application of human factors to equipment design does more good than do these motivational campaigns. He starts out by classifying the majority of human errors according to the following categories: (1) failure to follow procedures, (2) incorrect diagnosis of particular situations, (3) misinterpretation of communications, and (4) insufficient attention or caution. He then discusses the problem of tracing back the failure to determine its true cause. The problems of quantification of human error are discussed. The method of fault-tree analysis is described. A reasonable discussion is given of the negative aspects of, motivational and "crackdown" programs. This is a highly readable paper addressed to an important reliability problem. The author's suggestion that human-oriented engineering throughout design can enhance overall system effectiveness seems very reasonable and worthy of consideration. While no bibliography is given in the paper, it is indicated that a selected bibliography will be furnished on request from *Space/Aeronautics*.

R68-13937 ASQC 831; 873
AUTOMATIC AVIONICS TESTING.
David A. Findlay (Conover-Mast Publications, Inc., New York, N. Y.).
Space/Aeronautics, vol. 49, Apr. 1968, p. 75–81.
(A68-26859)

General survey of several automatic test equipments (ATE) used in the repair of aircraft avionics systems. The three ATE systems investigated are the Navy's Versatile Avionic Shop Test (VAST), the Army's Depot Installed Maintenance Automatic Test Equipment (DIMATE), and the Air Force's General Purpose Automatic Test System (GPATS). These systems are all designed to reduce turnaround time for avionics black boxes and to eliminate the proliferation of special-purpose test sets that now accompany almost every new piece of gear that is delivered to the services. All three systems operate on a similar basic format. A computer applies known inputs to the equipment under test. The output is measured under these conditions and is compared to stored limits. If the test is good, the computer proceeds to the next instruction. IAA

Review: This is a good review paper on automatic test equipment; it does not go into details, but rather is suitable for a quick appraisal of the problems and advantages of the state-of-the-art. It will be useful for managers and design engineers who need to be reasonably sure that they have a grasp of what is going on, but who are not at the moment interested in any of the gory details. (In one of the quotations an engineer states that a computer cannot be programmed to observe a signal which is jiggling. Probably what was really meant was that it is not economically feasible at the moment to do it. As soon as any function is sufficiently well defined, then—if the transducers are available—a computer can be programmed to sense it.)

R68-13938 ASQC 838
PICKING THE REDUNDANCY LEVEL OF FLIGHT CONTROL ACTUATORS.
F. E. Neebe (General Electric Co., Defense Electronics Div., Avionic Controls Dept., Binghamton, N. Y.).
Space/Aeronautics, vol. 49, Apr. 1968, p. 90, 92–94, 97, 98.
(A68-26861)

Study of the requirements involved in choosing the configuration of a redundant actuator for aircraft flight control systems. Such devices as the dual fail-off actuator, the dual side-by-side actuator with electronic model, the double fault-correcting actuator, and the dual-tandem actuator with hydromechanical model are examined. Block diagrams of these devices are included. IAA

Review: This paper is concerned with the problem of selecting the redundancy level for a particular system, the flight control actuator, and the details in the paper pertain to various configurations of that system. The material is concisely presented and clearly illustrated. The paper will therefore be of interest to design engineers concerned with flight control actuators. In a broader context, the paper serves as an illustrative case history for designers concerned with aerospace systems and the objectives of minimizing complexity while meeting specified performance requirements. The paper is a self-contained discussion, and no references are cited.

R68-13939 ASQC 838
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
RELIABILITY OF ANALYSIS OF CIRCUIT ELEMENTS BY THE REDUNDANCY METHOD
Zhen-Ming Chai 3 Aug. 1966 30 p refs Transl. into ENGLISH from Wu Li Hsueh Pao (Peking), v. 20, no. 8, 1964, p. 705–719
(FTD-TT-65-1052; TT-67-60263; AD-643922; N67-17644) CFSTI: HC $3.00/MF $0.65

The effectiveness of using the redundancy method to increase the reliability of circuit elements is analyzed, taking into account the possibilities of short-circuit and open-circuit failures. Formulas and curves of reliability gain under various conditions are derived from the analysis of circuit elements of both switching and nonswitching types. The effects of failures of some of the basic elements within redundancy elements in changing the loading of other elements have also been considered. Some discussion is devoted to the average life of the redundancy element, indicating that the redundancy method is particularly suitable for long-term operation or self-adapting systems. Some design considerations for practical applications are discussed in substantial detail with illustrations. Author (TAB)

Review: The title of this report got mixed up in the syntax grinder somewhere and should be "The Analysis of the Reliability of Redundant Circuit Elements". The first part considers various combinations of contacts which can be either open or closed, or failed and appears in several places in the English-language literature. The second part is nominally concerned with similar arrangements of elements which have values over a wide range, such as resistors and capacitors. The treatment is quite elementary and simple. The third section involves statistical dependence of failures, wherein the hazard rate of remaining elements is increased when some fail; the analysis is extremely simple and limited. Since the equations are virtually impossible to read (because of the small type and lack of resolution), since some of the tables are not translated from the Oriental symbols, and since this material will be found readily, in the English-language literature, there is no point at all in anyone reading this paper.

R68-13940 ASQC 832
Bunker-Ramo Corp., Canoga Park, Calif.
THE UTILIZATION OF HUMAN FACTORS INFORMATION BY DESIGNERS Technical Report, Dec. 16, 1965–Sep. 15, 1966
David Meister and Donald E. Farr 16 Sep. 1966 105 p refs
(Contract Nonr-4974-00)
(AD-642057; N67-15359) CFSTI: HC $3.00/MF $0.65

Three design tests were developed to determine how human factors criteria and information are applied to design problems. Each 4-hour test was administered individually to 20 designers. Test results indicate that designers have little or no interest in human factors and usually fail to apply human factors criteria to design. They do not read human factors handbooks. Design analyses appear to be quite primitive, being largely determined by spatial constraints and experiential stereotypes. Designers have difficulty in anticipating operational problems that may result from design parameters and are unable to evaluate completed designs. Design managers are somewhat more sophisticated in their design analyses than designers, but only slightly so. Both designers and human factors specialists were highly consistent in their responses. The most important source of information for the designer is the design specification. Where a designer does not have formally assigned responsibility for a design parameter, his analysis will not reflect this factor. It is recommended that design specifications emphasize human factors to the same extent that other functional requirements are emphasized. The format of handbook material directed at designers should be simplified, and contain procedures for analyzing design problems and examples of the application of information to these problems. Author (TAB)

Review: While many designers might object violently to the conclusions that are easy to infer from the report, namely that designers give some lip service to human factors but rarely if ever use it, the conclusions are probably all too true. The same statement could easily be true of other design considerations which are not traditional for designers, e.g., reliability and safety engineering. In defense of the designer it can be said that if he were to consider everything, in as much depth as the practitioners of the particular disciplines insist upon, he would never get a design onto the board, much less off of it. But human factors are important to reliability, since human failings are often of much more severe consequence in the malfunctioning of equipment than poor equipment itself. Certainly a piece of equipment which is designed to be forgiving of human error will be much more reliable than one that is in effect hostile to the human operator. At the very least, we would like it to be neutral. (The broad inference about all designers that is easy to make is, of course, not justified on the basis of the report itself which deals only with a limited sample.) Reliability engineers can profit from reading the report, since it may enable them to learn something about the techniques of really communicating with designers. Those who wish to carry out similar tests can benefit from the prior experience. Designers who wish to take the time and see themselves can profit the most, if they would take the lessons to heart.

R68-13944 ASQC 832
Aerospace Medical Div. Aerospace Medical Research Labs. (6570th), Wright-Patterson AFB, Ohio.
APPLICATIONS OF HUMAN RELIABILITY TO THE PRODUCTION PROCESS
David Meister (Bunker-Ramo Corp., Human Factors Programs, Canoga Park, Calif.). *In* AFSC Symp. on Reliability of Human Performance in Work May 1967 p 33–45 refs

Production worker errors are related to system reliability, and characteristics that differentiate production error from operating error are considered. Factors that predispose to worker error are analyzed in the context of the production process as a man–machine system. The importance of workmanship as a problem area that requires behavioral investigation is stressed, and means of detecting errors and their causes are presented. The effect of production error on reliability is treated, and a tabulation is presented to indicate unreliability resulting from significant human-initiated failures. Observational analysis was made of the production process and the tasks involved. Mention is made of a group interview process, workmanship error rates, inspection error, and situational factors in inspection. The need for a systematic program of behavioral research in the production process is emphasized. M.W.R.

Review: This paper is concerned with workmanship error in production as a significant factor in system reliability. To place the characteristics of workmanship error in focus, it is contrasted with operating error. The author considers production in terms of its systems aspects in order to achieve full consideration of the potential causes of worker error. He also mentions emphasis on such factors as the human engineering design of machinery and tools, information handling and job instructions, as opposed to the more widely publicized aspects such as motivation programs. Much of the discussion is concerned with methods of determining when a workmanship problem exists and what the problem consists of. This is treated in reasonable depth, considering the length of the paper. For those who wish more detail on these points, the discussion is keyed to nine references. The paper does a good job of indicating the opportunity which behavioral specialists have to

make a significant contribution to systems development through the investigation and improvement of production processes. As the author indicates, this is by no means a simple task. There is a need for much behavioral research into production processes, and some of the areas on which such research should be concentrated are indicated at the end of the paper.

R68-13951 ASQC 835; 814
Rome Air Development Center, Griffiss AFB, N. Y.
COST RELIABILITY FACTORS IN HYBRID CIRCUIT PACKAGING
John E. McCormick Oct. 1966 23 p Presented at the 4th Ann. Natl. Electron. Packaging/Production Conf., New York, 21 Jun. 1966
(RADC-SP-66-9; AD-643969; N67-20189) CFSTI: HC $3.00/MF $0.65

Factors that affect reliability, (1) materials, (2) chip mounting techniques, (3) connecting techniques; a comparative reliability rating; factors that affect cost, (1) assembly techniques, (2) alinement techniques, (3) repairability, (4) yield; comparative cost rating; hybrid packing figure of merit. TAB

Review: This paper develops two or three figures of merit for hybrid circuits (combination of silicon chips and thin films). These figures of merit are relative measures of cost, reliability, and the ratio of the two. The analysis is not unreasonable per se, but it is not the only one that could be done. The chief way to evaluate this kind of procedure is to see how it checks with other judgments on the same structures. Then resolve the discrepancies by changing either the other judgments or the method of analysis (or both). The experienced engineer will have little trouble putting this study in perspective, but the novice may tend to view it as a science rather than an art. Figure 1 which lists the properties of materials including silicon should not be used for the properties of silicon. The correct ranges of values are: thermal expansion 2.2 to 3.7 $\times$ 10^{-6}/°C; thermal conductivity .43 to .12 cal-sec/°C-cm; dielectric constant 11.7. The variation in the first two is made up of a temperature effect (which is reasonably strong in both cases although of opposite direction) and an uncertainty due both to measuring techniques and to varying properties of silicon from sample to sample.

R68-13954 ASQC 831; 872
Joint Publications Research Service, Washington, D. C.
THE PROBLEM OF SERVICING COMPLEX TECHNICAL SYSTEMS, I
Ye. Yu. Barzilovich *In its* Tech. Cybernetics, No. 6, 1966 14 Feb. 1967 p 102–125 refs
(N67-22410) CFSTI: HC$3.00/MF$0.65

A brief review is offered of basic works in the area of control of reliability of complex technical systems during operation and design. Author

Review: This is a qualitative review of various methods for servicing equipment. It considers both scheduled and unscheduled maintenance and various strategies for consuming redundant elements. There is a negligible amount of mathematics and, where it is convenient, the strategies are compared in terms of expected-number-of-failures/time, or total number of elements consumed. The translation is reasonably good, although the printing is so light on some pages that it cannot be read. There is an extensive list of 121 references—most of which are to English-language literature. If a legible copy can be obtained, this paper can be a valuable addition to any design engineer's library; it can help someone who wishes to know the kinds of situations that have been investigated or the kinds of repair to consider in order that the reliability of his equipment will be high. Thus this paper can be of use to designers.

R68-13955 ASQC 831; 817; 823
Joint Publications Research Service, Washington, D. C.
A METHOD FOR DETERMINATION OF THE OPTIMAL DISTRIBUTION OF RELIABILITY AND INDIVIDUAL ELEMENTS OF A SYSTEM
N. N. Kulakov and A. S. Zagoruyko *In its* Tech. Cybernetics, No. 6, 1966 14 Feb. 1967 p 90–101 refs
(N67-22409) CFSTI: HC$3.00/MF$0.65

A method is proposed for solution of two optimal problems by balancing the sensitivities of the system with respect to individual elements for different cases of increasing their reliability. When the problem cannot be solved exactly by the analytical method, a procedure is proposed for solution by the method of sequential approximation. In the majority of cases for sufficient approximation to the desired result it is sufficient to take no more than three steps. Author

Review: The problem being attacked is that of optimizing a figure of merit for fixed values of another figure of merit. For example, one can maximize the reliability for a given cost, or one can minimize the weight for a given reliability. Unfortunately, the relationship (for each one of the elements) of the variation in one figure of merit with respect to the other must be known. They are expressed in this paper as partial derivatives. One of the big difficulties is that these partial derivatives do not remain constant after the system is modified, so that all the values must be recalculated after every system change. Similar work is available in the American literature, with many proposed methods of solution. The translation in this paper is not difficult to read, but some pages are printed so lightly as to be almost illegible. A legible copy of this paper could be an asset to a designer, although he should not feel constrained to use one of the methods in it. Not all of the mathematics was checked, but it appears to be competent.

R68-13958 ASQC 831; 838
SOME NEW RESULTS ON THE CONVERGENCE, OSCILLATION, AND RELIABILITY OF POLYFUNCTIONAL NETS.
Rocco H. Urbano (USAF, Office of Aerospace Research, Cambridge Research Laboratories, Data Sciences Laboratory, Applied Mathematics Branch, Bedford, Mass.).
(Annual Symposium on Switching Circuit Theory and Logical Design, 5th, Princeton, N. J., Oct. 1964, Paper.) IEEE Transactions on Electronic Computers, vol. EC-14, Dec. 1965, p. 769–781. 5 refs.
(A66-21691)

The properties of m $\times$ 1 homogeneous polyfunctional nets under iteration (a growth process in which each element is replaced by a copy of the original net) are explored in considerable detail. Theorems are proved which relate the sequence of sets of output functions of a net to its structure as well as to the set of functions performed by the elements of the net. A complete characterization with respect to convergence of the 2 $\times$ 1 bordered net is given. Many new results on the oscillation properties of these nets are obtained, including methods for constructing nets which oscillate with prescribed period. The reliability properties of nets whose initial function assignments contain sum, product, and majority functions are studied. For the class of m $\times$ 1 bordered nets (nets only slightly less general than the m $\times$ 1 nets) it is shown that arbitrary reliability for these functions can be obtained under extremely broad conditions. Author (IAA)

Review: This is definitely not a paper for the casual reader; its greatest fault is the way in which the material of practical value is buried in a groundmass of mathematics. The results are not only new, but highly interesting. The author could have improved the usefulness of the paper by gathering these results into a summary. Since they have considerable merit, and since this is a continuing work of this author, a future paper might summarize the work which has been completed to that date. This reviewer agrees with the author's other critics that "poly-functional" is a more descriptive term for these nets than "neural". One cannot help but wonder, however, what effect this midstream change will have. (This is an additional argument for the summary paper.)

84 METHODS OF RELIABILITY ANALYSIS

R68-13915 ASQC 844; 775; 851

Navy Electronics Lab., San Diego, Calif.

IMPROVED HIGH-SPEED INFRARED MAPPING FOR RELIABILITY ASSESSMENT OF MICROCIRCUITRY Research and Development Report, Feb. 1965–Apr. 1966

H. F. Dean 1 Sep. 1966 48 p ref

(NEL-1399; AD-645664; N67-22682) CFSTI: HC $3.00/MF $0.65

Describes modifications to equipment and improved capability in IR mapping since first-generation system described in NEL Report 1272. High-resolution test mappings were successfully made at map-to-object magnifications up to 144x, in 3 minutes, and at environmental temperatures of 45°C to 55°C. Author (TAB)

Review: This report describes the infrared measuring system which can be used to map the temperature of a device. As such it is of value mainly to laboratory personnel involved in such testing, rather than design engineers, per se; although of course the latter can benefit from the improved instrumentation. For other than laboratory people, the report is best reviewed by quoting the results: "(1) Improvements have been made to the first generation IR mapping system developed for reliability assessment of microcircuits. The equipment consists of a cryogenically cooled IR detector, a scanning mechanism, electronic circuitry and a facsimile recorder. (2) Thermal map-to-object magnification ratios of 18×, 36×, 72× and 144× are available. (3) High-resolution maps of microcircuits can be made at magnifications of 144× in 3 minutes and at environmental temperatures of 45°C to 55°C." These improved techniques are important and many people have high hopes for these kinds of analyses of microcircuits, in lieu of classical tests-to-failure for uncovering defects.

R68-13917 ASQC 844; 090

RANDOM LOAD FATIGUE TESTING—A STATE OF THE ART SURVEY.

S. R. Swanson (MTS Systems Corp., Canada).

Materials Research and Standards, vol. 8, Apr. 1968, p. 10–44. 191 refs.

(A68-24659)

Study of test data obtained from random-load testing. Acoustic-fatigue and random-load crack-propagation testing are examined, as well as test loading involving groups of constant-amplitude cycles or individual cycles usually employed in a computer-randomized sequence of varying load level. The results of a questionnaire submitted to various technicians engaged in random-load fatigue testing are reported for the purpose of showing the nature of the work presently being done with random programed constant-amplitude equipment, as well as work in other areas of random-load fatigue testing. Recommendations for further developments in this field are given. IAA

Review: This extensive report is in the form of a literature summary. The field is not sufficiently well advanced to enable the material to be presented independently of the work of various people. The article is not easy reading; many of the terms, even though well defined by the author and the glossary, will be unfamiliar to the engineers who wish to make use of this paper; therefore they must study it rather than just read it. (Much of the discussion refers to the aircraft industry, although not in a parochial way.) There have been extensive developments for cumulative damage formulas to replace the linear hypothesis and which use the conventional SN curves. Advocates of those formulas, especially their own, will probably not be as ready to give them up as is the author of this survey. It is important to remember, as is brought out continually throughout the article, that random loading does not mean that one has absolutely no idea of which load will come next, but that many different kinds of random distributions are available, and that correlation, stationarity, etc. of the distributions must be taken into account. Anyone who is involved in extensive fatigue testing should be aware of the contents of this paper. There is a bibliography of 90 papers for both detailed references and educational opportunities. The author is most often careful to distinguish between her personal opinion on some phase of the subject and what is generally accepted; so the article can be considered reasonably fair. The article does not imply that everyone should stop constant-amplitude load testing and jump on the random bandwagon since there are still many applications wherein constant amplitude tests may be quite satisfactory. Reliability engineers, as well as design and fatigue engineers, can profit from studying this paper.

R68-13918 ASQC 844; 770; 873

ACE: THE ULTIMATE IN FAILURE DETECTION.

Ralph Dobriner (Hayden Publishing Co., New York, N. Y.).

Electronic Design, vol. 24, Nov. 22, 1967, p. 49–67. 6 refs.

The role of computers in implementing Automatic Checkout Equipment (ACE) is discussed, and the growth of ACE and its many uses are stressed. It is noted that better displays are emerging as the volume of data obtained by ACE has increased, and the need for passive sensors for the ACE of the future is discussed. Major trends in ACE are summarized as a gradual shift from sequentially controlled programmed systems to fully computer-controlled ACE, greater use of checkout equipment built into the primary system, increased use of telemetry instead of hardline data transmission, and development of ACE systems that will alert users to both component and system failures before they occur. Experiences with Apollo project are reported, and the workings of a typical ACE system are described. The black box, or Mark 2, that is built into the F-111 aircraft is described, along with efforts by commercial airlines. Mention is made of infrared checkout, interference techniques, and acoustical and radioactive sensors. M.W.R.

Review: Automatic checkout is a growing field and has been found to be very useful, e.g., the debates on automatic versus semiautomatic checkout appear much less frequently in the literature than they did several years ago. This paper is a summary designed for those not too familiar with the field and for managers who do not have the technical depth to appreciate a different kind of article. In general, it serves its purpose well. It is written largely in a positive vein although from time to time small portions are inserted which discuss the difficulties. Anyone who is reading this report to find out how to dive in and automate all of his own

checkout had best take the experience of some of the airlines to heart. They have been going much more slowly on this than they thought they would because of the problems involved. Even though the debates on automatic versus semiautomatic checkout have declined of late, there is little doubt that any particular group should go through several stages of automating checkout rather than trying to jump into full blown automation the first time. One would have all of the difficulties that everyone experiences when trying to convert an operation from manual to computer, plus the ones peculiar to the field of checkout. Not everyone has agreed on the desirability of integrating checkout equipment completely with the original equipment. The introduction of tests points can make for unreliability even though it may make for easier maintenance. Furthermore, the use of central computers is under attack from some areas because, especially in military vehicles, it may make the system too vulnerable to loss of the computer. The dissidents prefer that some of the functions be federated rather than integrated. In short, the concept of automatic checkout is extremely important for reliability; this is a good general summary report on the subject, but the bias if any is toward optimism—perhaps the byword with regard to automatic checkout is "be optimistically skeptical."

R68-13921 ASQC 844; 851; 823

Research Triangle Inst., Durham, N. C.

INTEGRATED SILICON DEVICE TECHNOLOGY. VOLUME 15: RELIABILITY

C. D. Parker. May 1967 85 p refs

(Contract AF 33(615)-3306)

(ASD-TDR-63-316, Vol. 15; AD-655082; N67-35610)

Although some variations in reported failure rates result from a lack of standard conditions, the variations principally result from a difference in process control among manufacturers. Most failures result from surface-related failure mechanisms and interactions between the interconnection system materials. Of several interconnection systems that are in use, gold wire ball bonded to aluminum metallization is the most frequently used and is considered the most reliable at temperatures below 125°C. Two promising alternatives are the aluminum metallization–aluminum wire system and the molybdenum–gold metallization–gold wire system. Either of these could eventually prove to be the more reliable. Temperature accelerates most failure mechanisms and failure rates are usually stated at specific temperatures. Reverse biased junctions accelerate surface mechanisms and increased current accelerates bulk failure mechanisms. It is generally agreed that failure rates increase by approximately a factor of 10 between 25 and 125°C. Acceleration factors have not been estimated for stresses other than temperature. Screening techniques contribute significantly to the reliability of integrated circuits by eliminating potential failures from actual use. Drop outs from burn-in screening tests run several percent of a starting lot. TAB

Review: Proving the reliability of silicon integrated devices is difficult at the best and there appears to be a considerable difference of opinion between consumers and manufacturers on just what the state-of-the-art actually is. This report is generally good and comprehensive. Its main strengths are a very good discussion of failure mechanisms and a healthy skepticism about precise claims in the literature for high reliability. It has a few minor deficiencies, largely associated with the discussion of Arrhenius behavior, but the enumeration of these should not detract from the overall high value of the report: it can be read easily by engineers; there is a negligible amount of complicated mathematics in it; and it gives a good balanced picture of the present status of the reliability of integrated devices and where it may go from here. Some points to watch out for in reading the paper are the following. (1) Consumers and manufacturers tend to find different failure modes of an integrated circuit and tend to have a different approach to the interpretation of its reliability, perhaps naturally enough. This difference is not brought out in the report. (2) In many places the report assures that conformity to Arrhenius behavior was demonstrated. While this may in fact be so, it is often true in the literature that authors are extremely easy to convince that Arrhenius behaviour is occurring, even though a more skeptical person would wonder about the tremendous scatter or curvature in the points, or even the noticeable lack of points. Some of the discussion about what Arrhenius plots indicate seems to have been adapted uncritically from the literature. The equation for Arrhenius acceleration factors should relate to hazard rate rather than times-to-failure since the times-to-failure are random variables. The equation for the sum of two Arrhenius behaviors implies statistical independence between the two failure mechanisms. (3) Figure 5 is inconsistent with the assumption of the exponential distribution. It has again been adapted uncritically from the literature wherein the logNormal distribution was accepted. On the same figure it is not clear how curve 3 results from step-stress tests and again the author has apparently accepted without critical scrutiny statements in the literature which are in fact erroneous or misleading. (4) On the bathtub curve, the area of constant hazard rate is labeled random which implies that the infant and wearout failures are not random, whereas of course they are (this is a common mistake in the literature). Overall the report is very good and can be of great benefit to both design and reliability engineers, perhaps of greatest benefit to design engineers who can readily get from it the kinds of balanced information that they will need.

R68-13922 ASQC 844

RELIABILITY PHYSICS.

G. T. Jacobi (IIT Research Institute, Chicago, Ill.).

IEEE Transactions on Reliability, vol. R-17, Mar. 1968, p. 2–4. 20 refs.

A frame of reference for papers dealing with reliability physics is presented in these introductory remarks that deal with the historical origins and evolution of the field of reliability engineering. Various elements of reliability are related to prior art and to present systems applications, and some basic methodology is described. M.W.R.

Review: The word *physics* is often used by engineers when they want to refer to something less casual, less brute-force, more subtle and more basic than they have been accustomed to doing. The use of that word in Reliability *Physics* is no exception. Much of the work, if not most of it, is firmly and well contained within traditional disciplines, such as metallurgy and chemistry and is not physics except insofar as one wishes to call all of the physical sciences a subset of physics. So much for any wonderment that the title might engender in the minds of the uninitiated—the author does take some pains to explain that this new terminology may be confusing. The paper is a reasonable summary of what has happened in the field of reliability and why reliability engineers felt they must do more basic work in order to improve the product. The paper is, as intended, a good introduction to the rest of the papers in this issue and can profitably be read by the uninitiated in this field. It is worthwhile pointing out that in nonelectronic fields, for example, metallurgy, failed part analysis has been traditional for many years.

R68-13923 ASQC 844

AN OVERVIEW OF ELECTRONIC PART FAILURE ANALYSIS EXPERIENCE.

L. W. Wright (Jet Propulsion Lab., Pasadena, Calif.).

IEEE Transactions on Reliability, vol. R-17, Mar. 1968, p. 5–9.

The role of part (or component) failure analysis in systems development is discussed, along with the major causes of parts failures and case histories for electronic devices. The major portion of parts failures that have resulted in equipment malfunctioning are attributed to gross quality defects and misuse. Time/environment dependent failure mechanisms are generally more insidious, more difficult to pinpoint, and result in fewer equipment malfunctions. There are numerous time/environment dependent failure mechanisms which are not understood sufficiently to permit highly effective failure analysis in relation to current projects. Failure analysis can be applied as a rapid diagnostic tool to provide assistance in assessing the magnitude of parts problems and recommending corrective action to upgrade overall system reliability. The presented case histories detail experience with transistors, diodes, fused wire, wirewound resistors, transformers, and interconnections in electronic devices. M.W.R.

Review: Reading a paper like this makes one wonder just what is the point of all the sophisticated statistical and mathematical analyses that have gone on in the name of Reliability, when some of the largest causes of unreliability are stupid mistakes that people make, either of omission or commission. This paper makes its points readily and sensibly, it is easy to read and will be a good experience for those who feel the world is otherwise organized. The rather old adage that the way to high reliability is through infinite attention to detail is reinforced by papers such as this. This kind of paper appears periodically over the years in order to remind the experienced and to initiate the novice. While this paper is an excellent experience to read, it will be of little value as a permanent reference.

R68-13925 ASQC 844

PHYSICAL BASIS FOR EVALUATING THE RELIABILITY OF P–N JUNCTION DEVICES.

Jack S. Smith (Air Force Systems Command, Research and Technology Div., Rome Air Development Center, Griffiss AFB, N. Y.) and Joseph Vaccaro (Air Force Systems Command, Research and Technology Div., Rome Air Development Center, Reliability Physics Section, Griffiss AFB, N. Y.).

IEEE Transactions on Reliability, vol. R-17, Mar. 1968, p. 20–27. 13 refs.
(A68-27558)

Review of the present status of p–n junction theory, its relevance to device degradation, and the experimental techniques available for measuring intrinsic device properties. Limitations in the theory and additional development required to meet the needs of device reliability evaluation and prediction are considered. The role of modeling in evaluating device reliability is discussed. IAA

Review: The general thesis is a restatement of the physics of failure approach to reliability—improved reliability can best be achieved by identifying failure mechanisms and eliminating them where possible (as opposed to the sampling and testing methods of more conventional reliability). One way to carry this out is to develop a model for device performance under a variety of independent variables, note any discrepancies between the predicted behavior and the actual behavior, and finally postulate failure mechanisms to account for the differences. This concept sounds fine when expressed in general terms; the authors have considerable difficulty in attempting to illustrate it with a specific example. The review of p–n junction theory is too brief to serve any purpose; the equations given do not do the job the authors intended them to do. An added column in Table I showing the predicted functional form of each of the failure indicators would be useful. To do so would be more complex than just inspecting the few equations given. These equations are generally not self-explanatory. The definitions of symbols following Eq. 1 are incomplete or erroneous. The quantity E (described as field) changes continuously across even the simplest p–n junction. The question arises as to where one measures the field or how one integrates over the field to account for E in Eq. 1. The symbol n_p described as holes in n-type material actually means electrons in p-type material; τ_0 is a lifetime, not a concentration as given in the paper. The transition between Eqs. 1 and 2 is not adequate. The statements made are "the space charge width w(v) is allowed to appear instead of its assumed value kT/qE. In addition, the exponentials are replaced by unity since (1) is only an approximation." Following Eq. 3, the symbol E represents electric field, but in the same equation the symbols E_i and E_R refer to energies. This seems to be an unnecessary confusion factor. Eq. 5 needs a minus sign. Eq. 10 is incorrect as written, although if C_0 represents the capacitance (the authors define it as initial concentration), and is brought into the denominator under the square root sign, the equation then becomes dimensionally correct. Most of the terms in Eq. 12 are undefined; even people familiar with the literature might fail to recognize immediately that τ_{ox} is the oxide thickness. R_s appearing in Eq. 12 is not the same as R_s used in Eq. 9, although no definition is given. Most of these equations, gathered from diverse sources, serve no real function in this paper. The functional dependence of all the failure indicators is not immediately clear from the equations given, and it is this that one is looking for to compare both with the observed behavior of the failure indicators and with the functional form of the failure indicators as postulated by a specific mechanism.

R68-13932 ASQC 846

Naval Applied Science Lab., Brooklyn, N. Y.

RELIABILITY AND MAINTAINABILITY DATA-SOURCE GUIDE

Jan. 1967 254 p
(AD-659195; N68-10849)

This data-source guide identifies twenty-three Government reliability and maintainability data sources and over ninety-five sources of technical and scientific information for related engineering data. The technical coverage, mission, status, and the address of contacts associated with each data source are summarized in the guide. The guide tabulates responses received from 118 contractors in reply to a questionnaire prepared by ARINC Research. A matrix shows that ninety-four of the 118 had established reliability and maintainability data collection activities. Also presented is a review of the collected data, as to its utility, optimism, currency, and applicability to multicontractor use. Author (TAB)

Review: The results of a recent survey to identify data sources are presented in this guide. A broad concept or definition of the subject was used, resulting in a comprehensive guide. Thus the sources identified are for direct indexes as well as for supporting data and information. Of particular value is the fact that specific information is given regarding where to direct inquiries. This is a permanent reference item for those interested in reliability, maintainability and related areas.

R68-13941 ASQC 844; 824

FATIGUE OF SELF-HEALING STRUCTURE—A GENERALIZED THEORY OF FATIGUE FAILURE.

C. D. Nash, Jr. (Rhode Island University, Kingston, R. I.).

American Society of Mechanical Engineers, Winter Annual Meeting and Energy Systems Exposition, New York, N. Y., Nov. 27–Dec. 1, 1966, 4 p. 7 refs.
(ASME Paper 66-WA/BHF-3; A67-15399) Members, $0.75; Nonmembers, $1.50.

A mathematical model is developed for the damaging effects of repeated trauma on self-healing biological structure. Terms are included for damage induced by aging and disease as well as the reduction in effective damage due to healing. This leads to an equation of the form $D = D_M + D_S + D_A - H$, where D represents the total damage at any time, D_M the damage associated with disease, D_S the damage due to generalized stress, D_A the irreversible damage due to aging, and H the damage repaired by healing processes. A linear theory is developed in which the various damage terms are independent of each other. In the general case, it is noted that interaction may occur between these damage terms, making them functions of one another. Author (IAA)

Review: This very short paper treats an extremely simplified model for fatigue failure of a system. The words are slanted toward a biological structure, but the mathematics would be the same even if it were a piece of steel. The title is somewhat grandiose and could easily mislead a mechanical design engineer into thinking that many of his fatigue problems were solved (it is an ASME Publication). But the theory itself is largely phenomenological with mathematical abbreviations used for some of the words. It is a linear theory, uses linear cumulative damage, and suggests that in practice interactions may be important but does not go into them. Negative damage is considered and while it is called healing in biomedical engineering, it is called annealing in mechanical engineering—mathematically they are quite similar. Apparently the paper is intended to introduce the concepts of mechanical fatigue and annealing to the medical profession and to biomedical engineers. It may serve this purpose admirably, but the equations are among the most simple that can be found in the theory of fatigue.

R68-13942 ASQC 844; 775
General Electric Co., Waynesboro, Va.
RADIOGRAPHIC TECHNIQUES FOR RELIABILITY SCREENING OF RELAYS
W. H. Lesser, R. A. Holcomb, and G. F. Trojanowski 30 Sep. 1966 66 p
(Contract NAS8-20301)
(NASA-CR-83535; N67-23261) CFSTI: HC$3.00/MF$0.65

The use of X-rays for identifying and locating defects in hermetically sealed relays is described. Three views through the three coordinate axes are required to detect all defects, although not all may be usable for relays with very high density sections. The radiographic methods were found to detect successfully metallic defects such as tramp metal, solder balls, weld flash, incomplete assemblies, and extra or damaged parts. The radiographic examination did not reveal the presence of low density contaminants such as hair, lint or insulation. Misaligned components and copper wires in excess of 0.002 inch diameter were readily discernable. The X-ray technique was found to be particularly effective for examination of blind final assembly operations, such as internal welds from can to frame and seal-off hole soldering. Details are given on optimum exposure and target to film distances. N.E.N.

Review: For those who are not directly engaged in research on non-destructive testing, the main message of this paper is given in the summary, namely, the X-raying of sealed relays can detect many kinds of defects and for some particular kinds of defects it is extremely effective. The report lists the difficulties involved and analyzes many of the techniques for carrying out the tests. These will be of value to laboratory personnel. By and large it is people who are interested in the laboratory techniques for whom the paper will be of value. It will be of little value, except as noted above, for design engineers. There is no discussion of the economic problems involved.

R68-13946 ASQC 844; 775
National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
ULTRASONIC EMISSION DETECTOR EVALUATION OF THE STRENGTH OF BONDED MATERIALS
James B. Beal *In its* Res. Achievements Rev., Vol. II, No. 5, 1966 p 19–27 refs
(N67-27755)

A program to measure adhesive bond strength was conducted. A study into the causes for weak adhesive bonds was made to determine the best methods of nondestructive testing of the adhesives. The discontinuities in the bond layer are discussed and related to ultrasonic signals. Bond stress methods and possible test techniques are listed. The measurement of bond strength by producing consistent weak bonds and the causes for the weak bonds are discussed. Fabrication of test samples are presented. The operation and capabilities of the ultrasonic emission detection equipment are explained, and the advantages and disadvantages of the equipment are listed. Author

Review: A more extensive discussion of the topic of this brief report is found in the paper by the same author covered by R67-13505.

R68-13947 ASQC 844; 821; 872
MINIMUM DOWNTIME AS A FUNCTION OF RELIABILITY AND PRIORITY ASSIGNMENTS IN COMPONENT REPAIR.
Daniel C. Denby (Virginia Polytechnic Institute, Dept. of Statistics, Blacksburg).
Journal of Industrial Engineering, vol. 18, Jul. 1967, p. 436–439. 3 refs. Research supported by Technical Operations Research and N.I.H.
(Grant 5T1 GM 2-10)

A troubleshooting technique for a system or assembly that fails when the cause of failure is not immediately obvious makes use of probability of failure or relative weights assigned to each suspected component of the system or assembly that has failed. The technique permits calculation of the sequence that will minimize downtime, which is considered as a function of reliability and priority assignments during component repair. An example is included for an electronic system that has failed, and for which past experience has indicated that one of three components was the cause of failure. The sequence in which the three components should be examined is determined so that a minimum amount of time will be expended in determining which of the parts is defective. Maintenance time distributions are derived, and both discrete and continuous distributions are plotted. M.W.R.

Review: This article described in reasonably simplified language a procedure for troubleshooting in a system or assembly in order to find a fault with minimum downtime. A necessary input is a reliability index for each component in the system which may fail; otherwise, the article is concerned more with maintainability than with reliability. The discussion deals with the finding of the expected repair time for each possible procedure. No actual optimization procedures are discussed, although it is remarked that dynamic programming is applicable. The case treated is the simple one of a system of components in series. Thus the paper is suitable as a rather elementary introduction to the subject, but those readers who want to consider more realistic refinements will do well to search the Operations Research literature, in which the subject of optimum procedures for detecting faults has received some attention. No references to any of this work are given in this paper.

R68-13948 ASQC 844
IIT Research Inst., Chicago, Ill.
FAILURE MECHANISMS IN RESISTORS Final Report, 3 Feb. 1965–3 Jun. 1966
F. R. Hand, M. Goldberg, and W. Brennan Griffiss AFB, N. Y., RADC, Oct. 1966 106 p refs
(Contract AF 30(602)-3614)
(RADC-TR-66-495; E6042-14; AD-641858; N67-16370) CFSTI: HC $3.00/MF $0.65

The accomplishments in the study of the failure mechanisms in metal thin film resistors is presented. The films studied were of the same type employed by several of the major manufacturers of thin film resistive networks. Experiments were carried out to identify the principal physical mechanisms contributing to the degradation of these devices. Chief among these were homogenization of the film composition, stress relief, and ion migration. A computer analysis of manufacturers test data was carried out to determine the nature of the behavior function. The computer was also used to derive from experimental data, an empirical expression for the test resistors as a function of environment, deposition parameters, and time. As a part of this program, the Fourth Annual Physics of Failure in Electronics Symposium was conducted. An evaluation of the symposium is presented. Author (TAB)

Review: This report is a good example of the trials and tribulations which can be encountered in running a research project, and the authors are to be commended for listing their disappointments as well as their successes. Some papers tend to read as if the entire project was a planned and realized success from beginning to end. Attempts to deal with failure mechanisms are difficult at best; therefore the results shown here should be considered typical rather than exact. Those who are concerned with research in thin-film resistors as well as some kinds of physics-of-failure, can profit from this report, not only from the positive results which were obtained, but from the negative ones as well. It should be pointed out that those statistical designs which have no replication call for certain kinds of assumptions about the data—assumptions which are not discussed in the report. Presumably the scientists on this project had statistical assistance in carrying out these tests, and those who would like to run similar tests are well advised to do likewise. The report will have negligible value for design engineers and those reliability engineers who are concerned with hardware rather than with research.

R68-13956 ASQC 844; 770; 838
Westinghouse Electric Corp., Baltimore, Md. Surface Div.
RESEARCH ON FAILURE FREE SYSTEMS Final Report
Dec. 1966 109 p
(Contract NASw-572)
(NASA-CR-80826; WGD-38521; N67-14217) CFSTI: HC $3.00/MF $0.65

Details are given on the development of techniques for efficiently allocating a limited number of test points within modularly redundant digital systems, and an estimating system reliability based on the results obtained from limited testing. The block model technique, based on the concept of coherent systems, is used for the reliability analysis procedure. In the test point allocation procedure, the system model used is the block reliability model. This technique permits optimal allocation of the limited number of test points within a redundant digital system. Both procedures were programmed in Fortran IV for implementation on a general purpose digital computer. Descriptions of these two programs are given. To illustrate the applicability of the computer programs to practical systems, they were applied to the modularly redundant Mariner C spacecraft sequencer; tabulated data on the results are presented. M.G.J.

Review: The title is somewhat more general than the report itself, but the purpose clearly defines the scope, so there is no difficulty; the work appears to have been well done and to be well reported. The limitations of the method are generally clearly spelled out—except for two assumptions in the reliability calculation: (1) good/bad is assumed to be a sufficient description for each element, and (2) testing is presumed to be perfect, i.e., good units always show good, bad units always show bad, and the test does not damage anything. The computer program for effecting the analysis appears to be reasonably documented so that an experienced programmer will have no difficulty in modifying the program for his machine. Some of the explicit assumptions made in both sections of the report (calculation of reliability, and location of test points) can be rather restrictive in application, and engineers should not assume that these are in fact the best assumptions. Much progress can be made in this type of research by careful choice of assumptions and criteria-for-success. This is not to say that the assumptions made by the authors in this report are unsatisfactory, it is merely to place the problem in perspective. The ones made by the authors appear quite reasonable and useful. Design engineers whose problems coincide with the one treated here will find this report of direct value.

R68-13957 ASQC 844
General Motors Corp., Indianapolis, Ind. Allison Div.
RELIABILITY EVALUATION OF TRANSMISSION GEARS
W. E. Schilke *In its* Allison Res. and Eng., Vol. 12, Fourth Quarter 1966 1966 p 8–21 refs
(N67-16176)

Reliability evaluation as it applies to transmission gears is discussed, and emphasis is placed on the pitting fatigue mode of failure. A general form of reliability formula is given, and the various modes of failure in gearing are considered. The loss-of-drive tests are described, and R/S/N curves are presented for loss-of-drive due to pitting fatigue. The recording and analysis of transmission duty cycles as applied to gears are discussed, including reliability calculation for constant stress and speed, cumulative damage, damage capacity and damage rate, effective stress, reliability calculation for variable duty cycle, and use of a digital computer in evaluating gear reliability. Finally, trade-off methods for improving the reliability of a transmission assembly are discussed. L.E.W.

Review: This paper is typical of many which appear on the subject of mechanical reliability. It uses the three-parameter Weibull distribution for times to failures (apparently in the actual data the authors use only the two-parameter Weibull distribution) and linear cumulative damage. As is also common in articles of this type, the author was careless about the assumptions of statistical independence in the calculation of "least squares" lines and with the demonstration that certain lines should in fact be straight. Specific examples of these difficulties are the following. (1) The use of unweighted least-squares to calculate the parameters of the straight lines on Weibull paper has two difficulties, (a) the points are not statistically independent as one would ordinarily wish, and (b) it is highly unlikely that the points would all have the same weight since the data have been considerably transformed from their original distribution. About the only value the author's procedure has over an eyeball line is that in his way everybody gets the same answer. (2) No residuals were calculated, that is, no attempt was made to compare the calculated line with the actual data. (3) The curve for Weibull slope versus surface contact stress had an extreme amount of scatter. Factors in slope of over 1-1/2 occur from the line to some of the data points. Nowhere is this included in the subsequent curves. (4) The reliability-stress-N curves show none of the uncertainty that exists, even though unreliabilities as low as 10^{-5} are shown on the chart. The position

of the 10^{-5} line could easily be off a decade in terms of number of cycles. (5) In the cumulative damage theory, no consideration is given to which reliability curve is being used and to the fact that the stress-life exponent changes drastically according to the reliability. (6) In the calculation of the reliability of an assembly, the strengths and stresses of the individual components are considered to be statistically independent. While it could easily be true that the strengths of the gears are statistically independent, *the stresses on them are definitely not. In fact, given the stress* on any one gear, the stresses on all other gears can be calculated, given the knowledge of the geometrical parameters. Therefore using the product rule is quite incorrect. In short, while the arithmetic per se is correct and the basic engineering ideas appear to be useful, the analytic techniques leave much to be desired.

R68-13961 ASQC 844; 824

Bunker-Ramo Corp., McLean, Va.

TESTING FOR COMPLIANCE WITH RELIABILITY SPECIFICATIONS. A COST-TIME-EFFECTIVENESS PROBLEM

J. C. Grimberg 20 Sep. 1966 29 p ref

(Contract DA-36-039-AMC-00954(Y))

(Rept.-06-06-01; AD-652691; N67-34194) CFSTI: HC $3.00/MF $0.65

The purpose of this technical report is to discuss the problem of testing for reliability as a product quality feature, both for acceptance and assurance of reliability measurements, for the case of one-of-a-kind products when uninterrupted operations is a very important consideration. The introduction discusses this problem as distinct from the quantity production case and presents the need for product quality assurance. Under definition of terms, working concepts are presented and reliability is singled out as the principal contributor towards product quality. The ability of the product to meet designated quality requirements or its reliability is dependent principally upon the products design. Any deviation from the products designated quality due to manufacturing/assembly deficiencies can be taken care of by a quality control/zero defects program. Any deviations due to aging problems are predictable and can be solved by maintenance. The reliability of the product is not considered affected by these latter two causes—manufacturing/assembly or aging effects. TAB

Review: The report discusses the problem of reliability testing for product acceptance (compliance with specifications) and assurance of reliability measurements, when a single sample of the product is available for such purposes. The contents are about equally divided between conceptual definitions and quantitative considerations. The quantitative material is concerned essentially with the exponential distribution, which has received wide treatment in the reliability literature. Thus the report is essentially a brief presentation of material which is not new, although no references are cited. The discussion considers the fact that tests may result in low reliability figures which, although meeting acceptance specifications, imply still lower figures for reliability assurance purposes, at given levels of confidence. This report addresses a *particular* case of restricted interest and has no use as tutorial material.

R68-13963 ASQC 844

National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.

A NIKE FAILURE STUDY

Abrom Hisler Mar. 1966 28 p refs

(NASA-TM-X-55549; X-721-66-98; N66-33502) CFSTI: HC $3.00/MF $0.65

Sporadic Nike–Apache vehicle flight failures were viewed with concern prior to the first flight of the Nike boosted Aerobee 350 vehicle. The ensuing failure study, incorporating a functional sequence approach to reliability finally assessed the Nike malfunctions as induced by combustion instability and the "delta p" approach is advanced as a result. Nike assembly precautions were taken to avoid combustion instability failure modes as pinpointed by this "delta p" hypothesis. On June 18, 1965, the first attempt to launch the complete Aerobee 350 sounding rocket was a total success. Author

Review: This report describes the "functional sequence" approach used and the results obtained in a study for the purpose of determining the cause of malfunctions in flight of the Nike solid propellant propulsion system. It serves as a good illustration of a successful search for failure causes. Use is made of the necessary sequence of events for satisfactory performance to run down modes of failure. *It will be of interest to those concerned* with the design and reliability of solid propellant rocket motors and to those concerned with failure modes and effects studies on such motors. An earlier report on a similar topic by the same author was covered by R65-12299.

R68-13964 ASQC 844; 770

Army Electronics Labs., Fort Monmouth, N. J.

EXTENDED LIFE TEST OF SOLID ELECTROLYTE TANTALUM CAPACITORS

Herschel L. Stout Mar. 1967 15 p refs

(ECOM-2812; AD-652891; N67-32544) CFSTI: HC $3.00/MF $0.65

Capacitance, dissipation factor and dc leakage of solid electrolyte tantalum capacitors were measured at intervals throughout a 26,000-hour life test. Seventy-five percent of ten capacitors survived with no degradation in properties and no indication of impending wearout. All failures were associated with a measurement period, leading to the inference that discharging and recharging operations may be a failure hazard. Author (TAB)

Review: This is a very brief report, consisting of four pages of text, two tables, and two figures. However, it does serve the purpose of conveying the essentials of the life test mentioned in the title. Significant among the conclusions are the evidence that capacitance, dissipation factor, and dc leakage do not appear to be correlated with susceptibility to failure, and the fact that charging from a source of moderate impedance appears to be a serious failure hazard. The report will be of value to those concerned with the reliability of solid electrolyte tantalum capacitors.

R68-13965 ASQC 844; 782

Melpar, Inc., Falls Church, Va.

TROPICAL SERVICE LIFE OF ELECTRONIC PARTS AND MATERIALS Final Report, 1 Jun. 1965–31 May 1966

B. H. Dennison and W. B. Morrow Ft. Monmouth, N. J., Army Electron. Command, Oct. 1966 177 p refs

(Contract DA-28-043-AMC-01346(E))

(ECOM-01346-F; AD-641172; N67-16330) CFSTI: HC $3.00/MF $0.65

A report is made of an effort to evaluate the degree and *extent of degradation of selected electronic components in tropical* environments over an extended period of time. The components are the type commonly employed in the fabrication of equipment designed for tactical use by the armed services. The component complement consists of units with industry and service acceptance of over a dozen years as well as recent additions resulting from the pressure and trend toward microminiaturization. TAB

Review: This voluminous report contains much of the original, or near-original, data with regard to both the parts and atmospheric conditions; thus anyone who is interested in pursuing the results of this investigation in more detail can do so with this report. Even though it is labeled a final report, it is for one year of an approximately two-year study, so that many of the conclusions are not final. The report can be valuable for those who are planning similar tests because they can profit from the experience of another group (especially from information on what did not work). The report does provide information which reflects correlation between the extent of component value change as a function of the tropical environment and the reaction time constant of the component. This is provided from the long term two-year processed data as well as from a two-week drying out period at the conclusion of the two-year exposure. It is important that none of the components were operated during exposure, and that an attempt was made even before measuring any of the components to bring them back to laboratory conditions, especially to remove moisture (this is not to say the procedure is either good or bad, but rather that the details of it are important).

R68-13968 ASQC 845

Computer Applications, Inc., New York.

FARADA INFORMATION PROCESSING AND PRESENTATION STUDY. VOLUME 1: STUDY AND ANALYSES; VOLUME 2: COMPUTER SYSTEM MANUAL; VOLUME 3: OPERATOR'S MANUAL

Aug. 1966 212 p refs

(Contract-N123(62738)51870A(X))

(CAI-NY-6155; V. 1, V. 2, V. 3; AD-660251; AD-660252; AD-660253; N68-86488; N68-86489; N68-86490)

Development of engineering and statistical techniques for analyzing FARADA part failure rate data is described, along with the descriptive statistics and the computerized information processing and presentation system incorporating the developed statistical techniques. Analyses, results, conclusions, and recommendations from the study are detailed in Volume 1; and part/environment categories and codes were developed and applied to a subset of the FARADA data. A computerized system was developed that analyzes the categorized data by first grouping those part failure rates that are not significantly different from one another and then calculating a median failure rate and a confidence interval around this median for each statistical group. A procedure is included to show how FARADA users can locate data in tables and from failure analyses. Volume 2 details the set of programs that comprise the FARADA system. Block diagrams and flow charts are included for the eight tasks of the programs. Volume 3, the operator's manual, presents step-by-step operating instructions for running the FARADA system on the IBM 1460 and the IBM 7094. M.W.R.

Review: Data are always a problem and government-sponsored data programs and efforts such as represented by these reports comprise the backbone of reliability data. Broadly speaking, these reports are extensions of the MIL HDBK 217A type of reliability data. More specifically, they are keyed to Volumes 1A and 1B of the FARADA data program. Volume 1 of these reports covering study and analyses would be of the most general interest as it contains the engineering and statistical analysis. The engineering analysis is essentially a finer subclassification of part categories and usage environments, but still not as fine a classification as many would like and this is acknowledged in the report. Likewise the statistical analyses are refined ones. Both the engineering and statistical considerations are, of course, keyed to a computerized approach. This material in Volume 1 may be of interest to those concerned with the analysis of reliability data from individual projects and programs. Volumes 2 and 3, containing the computer flow diagrams, program listings, and computer operator instructions, are quite specialized in their contents and would be of less general interest.

85 DEMONSTRATION/MEASUREMENT

R68-13920 ASQC 851

THE APPLICATION OF OVERSTRESS TESTING-TO-FAILURE TO AIRBORNE ELECTRONICS—A STATUS REPORT.

Jacob J. Bussolini (Grumman Aircraft Engineering Corp., Reliability and Maintainability Control Section, Bethpage, N. Y.).

IEEE Transactions of Aerospace and Electronic Systems, vol. AES-4, Mar. 1968, p. 142–148.

(A68-25880)

Application of the concept of safety-margin design and overstress testing to the design of electronic equipment. Test results are presented which indicate the value of the overstress test-to-failure technique as a design tool and method of source selection, reliability improvement, and evaluation. It is shown that 65% of the failure occurring under overstress environments are duplicates of experienced operational failures. Improvements of 5 to 1 in reliability levels have resulted from application of results of overstress tests which consumed less than 200 hr of actual test time. The first in a required series of indices which may assist in the eventual use of overstress testing for reliability-index measurement are discussed. IAA

Review: A most useful kind of accelerated test is that wherein the severity level is increased to the point where failures occur. Those failures are checked to see if they would reasonably occur during operation; if so, steps are taken to correct the condition. In some cases the condition may be corrected regardless of whether it would occur in the field, simply to avoid its limiting this kind of test. The over-stress testing referred to in this report is apparently of that type. It is not clear, however, which (or which combination) of the following three kinds of failures are occurring, and whether or not it is important to distinguish between them: (1) reversible parameter change, (2) simple stress–strength model for failure, and (3) cumulative damage. It is also not clear what, if any, consideration is given to components which perform quite well and with long life up to a particular severity level and then completely quit. For example, some kinds of electrolytic capacitors and some transistors behave in this way. Even though this kind of accelerated testing will not cure all ills, it is extremely valuable. This paper is more a qualitative testimonial for it than a detailed discussion of it.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 8

Typical Subject Index Listing

PROBABILITY
Procedures for applying sequential probability ratio tests in analyzing checkout and support equipment
TR-3 c84 R68-12733

SUBJECT TERM | REPORT NUMBER | NOTATION OF CONTENT | CATEGORY NUMBER | *RATR* ACCESSION NUMBER

The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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B

C

D

E

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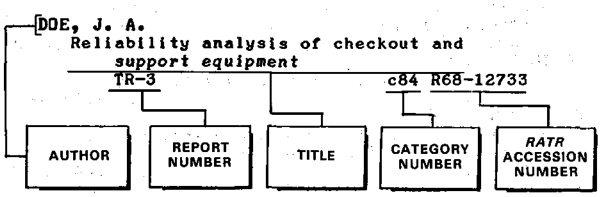
PERSONAL AUTHOR INDEX

Typical Personal Author Index Listing



The category number and the *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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REPORT AND CODE INDEX

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB*, *STAR*, and *IAA*, respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

ACCESSION NUMBER INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 8

List of *RATR* Accession Numbers

This list of *RATR* accession numbers may be used to identify the category in which a numbered abstract-review appears in the abstract section of this journal. Accession numbers are arranged in ascending order. Preceding each accession number is the category number for locating the abstract-review in the abstract section of *RATR*.

Reliability Abstracts and Technical Reviews

SEPTEMBER 1968

Volume 8
Number 9

R68-13969—R68-14020

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

ASQC CODES

***RATR* ACCESSION NUMBER**

CORPORATE SOURCE

R68-12733 ASQC 844; 413

TITLE

General Equipment Company, Banville, Calif.

RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT

PUBLICATION DATE

AUTHOR

John A. Doe 23 Sep. 1966 27 p refs

CONTRACT OR GRANT

(Contract NAS15-13411)

***TAB* AND *STAR* ACCESSION NUMBERS**

(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65

REPORT NUMBER

SALES AGENCY AND PRICE

***RATR* ACCESSION NUMBER**

R68-12739 ASQC 814

ASQC CODE

SEMICONDUCTOR RELIABILITY

TITLE

Joseph A. Smith (Eastern University, Arlington, Penn.)

AUTHOR AND AFFILIATION

Electric Journal, vol. 8, Apr. 1966, p 478–492.

JOURNAL REFERENCE

(A68-12569)

***IAA* ACCESSION NUMBER**

***RATR* ACCESSION NUMBER**

R68-12765 ASQC 773; 221; 823

ASQC CODES

TITLE

TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES

Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)

AUTHORS AND AFFILIATIONS

CONFERENCE OR SYMPOSIUM REFERENCE

Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p

Available from Assoc. of Reliability Eng., New York: $1.00

AVAILABILITY AND PRICE

***IAA* ACCESSION NUMBER**

(A68-12407)

VOLUME 8 NUMBER 9

Reliability Abstracts and Technical Reviews

A Monthly Publication

of the National Aeronautics and Space Administration

September 1968

80 RELIABILITY

R68-13982 ASQC 800; 810; 870

THE FUTURE OF RELIABILITY AND MAINTAINABILITY.

Leslie W. Ball (Boeing Co., Aerospace Group, Seattle, Wash.).

(AIAA Third Annual Meeting and Technical Display, Boston, Mass., Nov. 29–Dec. 2, 1966, Paper.) Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 177–188. (AIAA Paper 66-859; A67-12260)

Discussion of the theoretical and practical requirements for integration of reliability, maintainability, and all other engineering disciplines. The principle objectives of program management technology as practiced by DOD and NASA are defined, and reliability and maintainability are related to these objectives. IAA

Review: This paper is the same as the one covered by R67-13304.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-13975 ASQC 813; 844; 864

PROBLEM SOLVING FOR RELIABILITY IMPROVEMENT.

L. I. Medlock (General Dynamics Corp., Convair Div., San Diego, Calif.).

Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 63–69.

A management-oriented problem reporting and corrective action system is outlined that deals with functional hardware failures and operational problems that could affect the achievement of reliability goals. Administered by the reliability engineering department, the program requires the participation of all line departments. A reliability action center displays the program status graphically and a reliability review board makes management decisions and offers direction. The need for strong management is stressed, along with quick and positive corrective action. M.W.R.

Review: The author calls this a brief outline and such it is. Those who are acquainted with papers describing management techniques can more easily evaluate this type of paper than can the novice (for whom the paper was not designed) who is overly impressed with organization charts. The program as outlined appears good, and if it works as described, it is undoubtedly quite effective. Nevertheless, one can expect that just as the hardware program itself has problems, there are rough spots in the management and corrective action systems. The operation probably does not always flow as smoothly as is easily inferred from the paper. Another aspect for the novice to beware of is this statement "...treat every failure as important...". There are undoubtedly implied restrictions in this which are obvious to the author. For example, it may apply much more during later program stages than early in research/development. The fact that a reliability review board must approve the corrective-action decision does not mean much on its face. It depends on how detailed the level is at which the board considers the problem and on what level of detail they are capable of understanding the problem. This is not to say that the program does not function well and effectively, but merely that one cannot tell from the description of it whether it does or not.

R68-13977 ASQC 813

APOLLO RELIABILITY AND QUALITY ASSURANCE PROGRAM.

Catherine D. Hock (NASA, Office of Manned Space Flight, Apollo Reliability and Quality, Washington, D. C.).

Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 85–98. 7 refs.

Requirements of the Apollo reliability and quality assurance program, as presented in NHB 5300.1A, are discussed in terms of activities needed to achieve mission success and crew safety. Basic elements of the NHB 5300.1A plan involve (1) hardware reliability and quality assurance requirements during study, design, manufacturing and checkout; ground testing, static firing and checkout; state, module, and integrated testing; mission; and postflight; (2) implementation requirements for government offices, prime contractors, and subcontractors; and (3) additional requirements covering components and materials, data system, failure and defect reporting, criticality categories for testing, and flight readiness review activities. Various aspects of these activities are summarized in broad terms. M.W.R.

Review: The overview of the Apollo reliability and quality program which is given in this paper gives the impression of a

comprehensive effort. A difficulty with verbal and broad descriptions of programs is a tendency to use the same words for significantly different levels of effort. No mention is made in this paper of quantification of levels of effort or of other measures such as test results which would compare Apollo efforts with those of other programs. In any case, only the actual Apollo success record at the end of the program in the years ahead will measure the adequacy of the comprehensive program described here. Most certainly the NASA history of success in the earlier manned space programs has resulted in valuable guidelines for establishing appropriate levels of effort in the Apollo reliability and quality program.

R68-14014 ASQC 815

AN OVERVIEW—THE RELIABILITY OF AEROSPACE GROUND EQUIPMENT.

Richard E. Shafer (Professional Consultants, Inc., Los Angeles, Calif.).

Evaluation Engineering, vol. 7, May/Jun. 1968, p. 42–46.

Means of improving overall reliability of Aerospace Ground Equipment (AGE) are discussed, and various government specifications dealing with reliability are noted. Aerospace Vehicle Equipment (AVE) functions are identified to facilitate determination of the extent of AGE support required and effects of failure of AVE/AGE. Consideration is given to AGE/AVE interfaces, and AGE reliability is considered as a tool for both design and management decisions. Techniques detailed in MIL-R-26474 and MIL-HDBK-217 can be used for AGE reliability prediction, and MIL-STD-756 outlines methods for preparing reliability diagrams as well as some techniques for performing predictions. Factors which enter into the selection of appropriate techniques are discussed, and steps for improving AGE reliability are outlined. M.W.R.

Review: This overview article is suitable for novices in the reliability field, or managers who feel they must be concerned with reliability as a parameter, and perhaps for reliability engineers who like to browse. Reliability is, of course, very important in ground equipment and most of the important points are touched upon. The first part of the article is just testimonials to the need for reliability and the next part lists some of the functions and interfaces with the vehicle equipment. The remainder of the article is miscellaneous remarks on what reliability activities can accomplish, how numerical reliability can be predicted, and some means for improving reliability. The overview adequately represents many of the activities involved in the reliability discipline. In such a short article as this it is not possible to reasonably-criticize the emphasis. Most of the items listed as topics have to do with numerical reliability. One of the important aspects of any reliability engineering effort is paying attention to design details so that life is improved or a chance of having a defect is lowered, but without any quantitative means of figuring a probability associated with it. There are no references.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-13972 ASQC 824; 882

CONSTRUCTION OF AVAILABILITY MODELS.

Richard F. Johnson (Litton Industries, Data Systems Div., Reliability Test and Evaluation Section, Van Nuys, Calif.).

pectrum of Reliability: Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 1–25.

A basic model of availability is constructed for a system consisting of three subsystems. In one (a), failure can be discovered and repaired immediately; in the next (b), failure is discovered during a periodic checkout; in the third (c), failure aborts or inhibits the mission. For subsystem A it is assumed that there is a distribution of repair times for all failures whose mean times can be estimated. For B, there is no knowledge of the subsystem between checkouts unless the system is under repair; and it is assumed that checkouts occur at certain intervals whether the equipment is up or down. In c, any failure remains undetected during passive operation. Apparent versus true availability for self testers is discussed, and a method for differentiating between true and apparent availability is demonstrated. Effects of spares on availability is shown, and an example demonstrates the differences of reliability estimation using different models for the case of a hypothetical long range passive tracking system of a submarine sonar system. M.W.R.

Review: This is a tutorial paper which is written in some detail for several different kinds of repair situations. Not all of the mathematics was checked, especially that later in the paper, but it appears to be competent. The reader will need to understand the symbols for union and intersection of sets and should note that the author uses x for a multiplication sign upon occasion. For those who are concerned about the difference between reliability and availability, the distinction is made that reliability is the availability-without-repair. A person with a reasonable background in algebra and probability notation will find this paper a help in learning about availability formulas.

R68-13974 ASQC 823

SOME ASPECTS OF SEQUENTIAL ANALYSIS.

Leo A. Aroian (TRW Systems, Redondo Beach, Calif.).

Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 39–60. 29 refs.

Life testing using sequential analysis is considered, including use of the Poisson process, the binomial distribution, and approximations. Sobel-Tischendorf type of sequential life acceptance tests are described, and some examples are presented and represented graphically. Mention is made of the truncated binomial sequential tests, and essential formulas are presented for the binomial distribution. Operating characteristic curves obtained by the exact Poisson and the exact binomial, both with exponential lines, are compared. Life testing is considered in the event that the exponential does not hold, and some new methods of sequential analysis are discussed. M.W.R.

Review: The author is well known for his work on sequential analysis involving the exponential distribution, and this paper gives a very brief explanation of it plus other work in the field. An extensive list of references is given for further information. The paper is quite terse and those who do not have some familiarity with the field already will be hard pressed to learn much from it. The last two sections about new methods in sequential analysis are so terse that they cannot be understood without appreciable familiarity with the material. For further information on this topic see the author's paper in Technometrics, vol. 10, Feb 68, p. 125–132. Those who have enough background but are not yet experts on the subject can profit from reading this summary, especially since it is so copiously referenced. (A useful set of tables

for AGREE-type truncated sequential life tests is given in a paper by Arion, Cooper, and Petersen in Annals of Reliability and Maintainability, vol. 5, July 1966, p. 874–893.)

R68-13978 ASQC 824; 412
THE CONFIDENCE GAME.
Martin T. Pett (Hughes Aircraft Co., Missile Systems Div., Canoga Park, Calif.).
Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 101–110. 3 refs.

Confidence levels and likelihood estimations of reliability are discussed in terms of sampling and lot performance, and the limitations of small samples are noted. Conventional confidence defines the probability of prescribed test results as a function of reliability values, whereas likelihood is used to define the probability of specific reliability values as a function of test results. The assumptions that are necessary to compute likelihood are discussed along with their validity; and the use of equally likely *a priori* probability of reliability values is justified because it results in simplified calculations, yields conservative estimates, and appears to be an unbiased choice. Formulas for likelihood computations are included, and the applicability of likelihood computations are considered. M.W.R.

Review: The author has some worthwhile comments on the term "confidence" and points out that the term is used by statisticians in a particular technical sense. (For this reason it is worthwhile in articles for engineers to use the term "statistical confidence" when appropriate.) His comments on the need for using prior knowledge are also valuable. His specific formulation, however, leaves something to be desired. In particular, his formula is sensitive to the number of divisions into which one divides the unit interval. This seems unreasonable and can be avoided by using the a posteriori distribution as given by Bayes Theorem and performing the integration. The "Bayesian confidence" can be obtained very simply for the cells in Table 1 in this manner. The use of a *uniform* prior distribution can be deprecated on the basis that it is not really an expression of the engineer's feelings on the subject. Confidence limits can be associated with the Bayesian technique and again they are well defined by statisticians, although in this case in a way more useful to engineers than classical confidence. Thus, in this connection the value of this paper will be in confirming an engineer's idea that the classical statistician rarely answers the question the engineer actually wants to ask, but instead answers a related statistical question, hoping that the engineer will be able to make an appropriate interpretation of it.

R68-13979 ASQC 821
DETERMINING THE MISSILE OVERFLIGHT HAZARD.
Seymour L. Friedman (Hycon Mfg. Co., Monrovia, Calif.).
Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 113–122.

Probability of missile malfunction, missile impact probability density function, and impact and kill probability density function relative to land areas and population densities are considered in terms of the risks involved in launching missiles over the continental United States. Malfunction probability requires a circuit and mechanism stress analysis, failure rate determination, and circuit and mechanism parameter variability analysis in relation to the effects of the environmental conditions in the overflight areas. Missile impact probability density function is determined from its standard deviation and mean parameters for both range and bearing errors; and the method is presented for determining impact sensitive parameters at each level of system operation. (The failure probability distribution model for the system is also developed.) The method yields not only specific impact parameter data and the optimum range safety impact parameter excursion for use in an automatic range safety monitoring system, but delineates an experimental design for implementing an automatic monitoring system and test specimen hardware from which actual parameter values readout of the modules and submodules or components can be recorded and computed. M.W.R.

Review: It is difficult to see what the paper contributes, although this is not to say that the answers sought are not worthwhile. Too much of the paper is taken up with deriving elementary calculus and statistical formulas. Most engineers would have been satisfied as well by a simple partial differentiation of the original formula (using the differential approximation all in one step) and then using the formula (for uncorrelated variables) that the variance of the sum is the sum of the variances. Many of the formulas serve little useful purpose. It could as well have been said, for example, that the range and bearing are presumed to have Gaussian distributions and are statistically independent (which in the case of Gaussian distributions is equivalent to being linearly uncorrelated). The paragraph tacked on the end about Monte Carlo simulation seems to negate much of the earlier analysis.

R68-13983 ASQC 821; 882
PREDICTING OPERATIONAL READINESS BY COMPUTER ANALYSIS.
L. J. Schneider (Autonetics, Data Systems Div., Anaheim, Calif.).
Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 191–203. 5 refs.

A mathematical relationship between system failure rate and the probability that a system will be operationally ready or available is developed graphically on the basis of a Poisson distribution of arrivals and an exponentially distributed failure time. The basic model of queueing theory, based on the assumption that the arrivals and services in a queue can be mechanized as a Poisson process, was evolved; and multiple channel queues for finite populations were treated as a constant failure rate region with repairs on a first come first served basis. Practical application of the presented model is illustrated by simulated data for an antiaircraft missile system. Operational readiness was determined for a missile interceptor squadron comprised of 15 missiles, each of which averaged 680 operating hours per month. Two repair facilities and five-day, two-shift maintenance were assumed. Each failure required 7.2 hours to repair and mean operating life between failures was 50 hours. M.W.R.

Review: The purpose of this paper is to provide a graphical method that relieves the reader of dwelling on tedious mathematical details in making predictions of operational readiness. It serves as a useful introduction to the concepts for operational readiness (sometimes called availability). The only poor part of the paper is an introductory section on mortality, and it might have been well to dispense with that section entirely. If read only casually, and for no concern with details, it does provide useful information, however. The particular assumptions in the paper should be carefully noted because they are important in determining the solution. The formulas and tabulated numerics were not checked in detail, but on the basis of a spot check they appear to be correct.

R68-13989 ASQC 821; 844

Atomic Weapons Research Establishment, Aldermaston (England).

OVERLAP PROBABILITY OF FLAWS IN LAMINATED DIELECTRIC

W. Held and R. J. Klahn Mar. 1967 21 p refs Transl. into ENGLISH from Elektrotech. Z., issue A (Berlin), v. 87, no. 4, 18 Feb. 1966 p 121–126

(AWRE-TRANS-53; N67-34450) HMSO: 3s

The individual layers of highly stressed electrical insulation contain flaws such as conducting inclusions and pinholes. The probability of two, three, or more such flaws overlapping is calculated. In the dielectric of capacitors, overlaps of two flaws occur with a probability of 10^{-5} to 10^{-3} per m^2, while overlaps of three or more particles are highly unlikely. Results from power capacitor tests are compared with the calculated overlap probability of conducting inclusions in the paper. The technique used enables an estimate to be made of the test failure in capacitors with three layers of insulating material, provided the number of flaws in the paper is known. R.N.A.

Review: This paper treats a reasonably simple problem. The mathematical development uses a series of approximations; the final result is one which is more or less intuitively obvious. The simple-minded model is related to the practical situation and is shown by the text to be too simple-minded to be accurate. This conclusion agrees with the experimental evidence since the shape and kind of particles, etc., are important as well as their areas. The biggest values of the article lie in (a) its discussion of the fact that a more complicated model appears to be necessary in order to describe the situation and (b) the fact that the kinds of measurements which are probably important on the dielectric itself (in terms of the kind and nature of flaws) are seldom available. Only component-specialists who are interested in this or directly related problems will find this article of value.

R68-14009 ASQC 824; 431

Joint Publications Research Service, Washington, D. C.

EVALUATING THE RELIABILITY OF SYSTEMS WITH A VARIABLE UTILIZATION MODE

S. M. Brodi and O. N. Vlasenko *In its* Tech. Cybernetics no. 1, 1967 14 Apr. 1967 p 45–51 refs

(N67-24207)

A semimarkov process is constructed describing the functioning of systems operating in two periodically alternating modes. The relaibility characteristics (the average time and probability of trouble-free operation) of such systems are defined. Author

Review: This is another one of the calculations at which the Russians are so prolific. The case actually treated (title is quite general) considers a piece of equipment whose hazard rate alternates between two values. The period of time at each value is a random variable. During each such period the hazard rate remains constant, thus the equipment alternates between a high hazard rate and a low hazard rate. The quantities calculated are the reliability as a function of time and the mean time to failure; the results are given in terms of Laplace transforms. The mathematics was not all checked but it appears to be competent. With the number of these small calculations becoming large beyond all bounds it is difficult to keep track of them, especially when the Russian and American literature are included. Someone could perform a useful service by making a handbook which contains these many formulas.

R68-14010 ASQC 821

Joint Publications Research Service, Washington, D. C.

NUMERICAL CHARACTERISTICS OF THE PROBABILITY DISTRIBUTION FOR CORRECT OPERATION OF EMERGENCY SYSTEMS

V. V. Malev *In its* Tech. Cybernetics no. 1, 1967 14 Apr. 1967 p 69–79 refs.

(N67-24211)

Expressions are presented for the average time and dispersion of the time of emergency-free operation for emergency systems consisting of an arbitrary number of single type operating and reserve devices with a Poisson distribution law for failures in various cases of organization of checking and repair of devices. Author

Review: This paper deals with the operation of a protective device for a system. False alarms are considered to be statistically independent of failure-to-operate-when-required. The case of false alarms is disposed of readily since they are presumed to have an exponential distribution. The other situation which could be termed a catastrophe (the protective device does not operate when required) is treated in four special cases. The discussion is difficult to follow because of the language; for example, the phrase *emergency situation* is used in three completely different senses: (a) the catastrophe referred to above, (b) a simulated system failure, and (c) system failure. Four special cases are analyzed. Case 1 deals with a situation where no maintenance is performed; case 3 deals with the situation where maintenance is performed only after a catastrophe. It is not clear just how these two cases differ. Case 2 considers periodic checkout of the protective devices and case 4 considers periodic checkout of the protective devices combined with repair after a catastrophe. Again it is not clear how these two cases differ. Therefore since the answers are not the same the explanation of each case is inadequate to show wherein the real differences lie if the mathematics does not represent the described situation. The figure of merit derived in each case is a *mean time-to-catastrophe* and the *variance of the times to-catastrophe.* Before trying to use this paper it is suggested that the engineer try to find a similar problem treated in the English-language literature.

R68-14020 ASQC 824; 872

Joint Publications Research Service, Washington, D. C.

RELIABILITY OF REPAIRABLE UNRESERVED MULTIACTION DEVICES

Yu. A. Slepov *In its* Tech. Cybernetics no. 1, 1967 14 Apr. 1967 p 52–56 ref

(N67-24208)

Expressions are derived for the definition of the preparedness function and the unconditional probability of trouble-free operation in the time interval $(t, t + \tau)$ for any law of distribution of the time of trouble-free operation and repair time. Some special cases of the expressions obtained are investigated. Author

Review: This paper uses the convolution approach to calculate the availability of a repairable device under several common assumptions. The purpose of the term *multiaction* in the title is not known, since the device is presumed to be either good or bad. The statement that "repair completely restores properties" presumably does not mean that the device is restored to its condition at time zero but rather that there are no bad "repairs." Apparently the device may have a new distribution function after the failure and repair. The results are given in terms of Laplace transforms and are evaluated for the special case where the distribution function after each repair is the same for all devices and repairs, and then where that distribution function is the exponential. The general equations are not tractable and the tractable special solutions are similar to those which appear from time to time in the English-language literature. Therefore, this paper will be of no particular concern to reliability engineers or theorists except as an example of what the Russians are doing.

83 DESIGN

R68-13969 ASQC 832

Martin Co., Baltimore, Md.

CREW RELIABILITY AND ITS RELATIONSHIP TO SYSTEMS EFFECTIVENESS

Milton A. Grodsky Washington, Naval Material Command, [1967] p III-B-1 to III-B-19 refs Symp. on Human Performance Quantification in Systems Effectiveness, Washington, D. C., Jan. 17, 18, 1967 Sponsored by Navy and Natl. Acad. of Eng.
(Contracts NASw-833; NASw-1187)

Problems involved in operator performance are considered as they relate to systems effectiveness, and the inclusion of operator performance factors in reliability and maintainability models is considered essential to insure their validity. The systematic collection and analysis of operator performance data on a large scale is recommended, along with the development of models of man-machine performance and the initiation in military procurement procedures of detailed instructions to insure operator performance effectiveness. Criteria for operator performance, need for acceptable measuring systems, and methods of collecting data are noted. The synthetic task battery related to operation of aircraft systems is discussed, as are system task measures for lunar landing and lifting reentry simulations. A third technique considered is that of observations of human performance and errors. M.W.R.

Review: The major theme of this paper for reliability and design engineers is that *if the equipment needs to have an* operator, that operator must be considered in any assessment of reliability of the system. One point on which the author did not touch is that the traditional concept of reliability, which is usually a separation of the equipment into good or bad (with the equipment needing repair when it is bad), needs to be modified to account for the human operator. Often when the operator makes a mistake a subsequent retry by the operator will rectify the situation; therefore other measures of acceptable performance need to be developed. The operator tends to be neglected by the design group and the reliability group, although in the manufacturing area a reasonable amount of work has been done concerning operator performance; and in some high-reliability areas the manufacturing accuracy is extremely important. There is some jargon in the paper so that those not immediately familiar with the aircraft/flight fields will be uncertain about the meaning of some of the words. It is not easy to say who could benefit from reading this paper, but suffice it to say that this is the type of paper to which reliability and design engineers should be exposed occasionally. Those who are directly concerned with human factors would consider it a case history.

R68-13970 ASQC 832

Operations Research, Inc., Silver Spring, Md.

HUMAN-INITIATED MALFUNCTIONS

Gabriel Markisohn Washington, Naval Material Command, [1967] p IV-B-1 to IV-B-14 refs Symp. on Human Performance Quantification in Systems Effectiveness, Washington, D. C., Jan. 17, 18, 1967 Sponsored by Navy and Natl. Acad. of Eng.

Need for the quantification of human performance and for the conduct of human reliability research and analysis is emphasized because of the apparent significance of human-initiated malfunctions found in systems effectiveness studies. A set of accepted terms and definitions for human performance researchers is considered a first step, and it is proposed to limit the scope of human reliability analysis to the operational phase of the life cycle of a system, including both operation and maintenance. Types of human errors are discussed and some human-initiated malfunction data are presented. M.W.R.

Review Papers on human factors seem to concentrate on the fact that hardware reliability is much easier to calculate than operator reliability, and that there is a lack of data with regard to calculating human-operator reliability. It is noteworthy that the man who must make conscientious estimates of hardware reliability decries the lack of data and points out how difficult it is to find suitable models for reliability and to make anything other than ball-park estimates (unless the new equipment happens to be very similar to some recently-made gear). This paper devotes considerable space to the inadequacy of failure reporting forms from the human factors point of view. They are inadequate also from the hardware point of view; and the reliability literature is replete with new designs for failure reporting forms. This paper can be useful to design and reliability engineers and to those engaged in human-factors research by showing the difficulties associated with the present situation and what are some of the attempts to rise above it in the near future. Anyone who is looking for solutions, however, need not bother reading the paper.

R68-13971 ASQC 832

Bunker-Ramo Corp., Canoga Park, Calif.

DEVELOPMENT OF HUMAN RELIABILITY INDICES

David Meister Washington, Naval Material Command, [1967] p V-A-1 to V-A-24 refs Symp. on Human Performance Quantification in Systems Effectiveness, Washington, D. C., Jan 17, 18, 1967 Sponsored by Navy and Natl. Acad. of Eng.

Assumptions, characteristics, advantages, and disadvantages are described for the human reliability (HR) method of operator performance prediction; and attention is given to the means for collecting and analyzing data necessary for the development of human reliability predictive indices. Mention is made of attributive indices, reliability-oriented techniques, and computer-based methodologies; and the similarity between behavioral and equipment reliability concepts is considered. Since the HR approach is performance and output-oriented, it requires precise definition of the unit of activity being measured as well as the criterion of measurement. The mission or system must, therefore, be broken *down into its constituent functions; and description units must be* given for the various functional levels and for control/display equipment being acted upon by the operator. Application of the HR method requires not only the analysis of the system into discrete measurable units, but also the analysis of the behavioral unit, the assignment of predictive values to behavioral units, and the combination of unit probabilities into a unitary figure of merit. M.W.R.

Review: This rather long paper details the author's idea on what he calls the "Human Reliability" method of operator performance prediction. It is written for other human-factors people rather than for design or reliability engineers because it is long and detailed, and uses language and concepts peculiar to that field. People working in the human factors area are caught on the horns of the same dilemma on which those working in hardware reliability are caught, namely, the more accurately descriptive a model one gets of a system, the less able he is to use available data, so that one cannot make an accurate prediction. Where "quick and dirty" models are used, there are available correspondingly "quick and dirty" data to go in them but then the results are not accurate. This author has written extensively in the human factors field and this paper is an attempt to steer a reasonable course between the two horns of the dilemma. In the meantime, while such activities as this are building a good theoretical foundation, it would be worthwhile helping designers to do even the gross things that they are now doing rather than insisting that designers go through the whole gamut. Very likely if designers do everything in as much detail as every specialist thought the designer should, the designer would never get anything off the drawing board. The author does make a statement which would be easy to misinterpret. He suggests that rarely in design are switches put so close together, for example,

that one has difficulty operating the one without the other. But it has been reasonably well established that, especially in aircraft design, when the pilot is under stress the switches may be close enough together and/or so similar in operation that he can operate one when he intended to operate another because of the stress and time constraints.

R68-13976 ASQC 831; 612

DYNAMIC MECHANISM RELIABILITY BY MONTE CARLO METHODS.

Frank R. Van Wagner (International Business Machines Corp., Systems Development Div., San Jose, Calif.).

Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 71–82.

A method is presented for evaluating reliability or probability of successful operation of a dynamic mechanism by Monte Carlo methods, and two computer programs are described for use in a two-phase Monte Carlo reliability analysis. The reliability model is discussed, statistical considerations are considered, and the application of Monte Carlo methods to the solution of a complex problem is treated. Attention is given to conditional convolution; and to make the resultant expressions as simple as possible, it is assumed that the reliability analysis can be confined to one dimension. It is assumed that the mechanism is assembled from randomly produced parts so that each finished assembly deviates somewhat from nominal specifications and that 50,000 Monte Carlo trials are required to approximate the critical dimension probability distributions with sufficient accuracy. Trapezoidal integration was incorporated in the PLPCT2 program written in Fortran 4; and the basic Monte Carlo simulator in use is SIMX2, for which three versions exist. Version 1 is in Fortran 2 and has variable tape I/O assignments; version 2 is in Fortran 4; and version 3, which is experimental, is in level H 360 Fortran. M.W.R.

Review: This is a condensed statement of a problem and its solution. In order to understand it, one has to be familiar with some of the probability notation, especially conditional probabilities, and with terms like convolution. While the article may have served a useful purpose at the conference, it is doubtful that the printed paper will help anyone, unless they happen to be browsing through the proceedings and become interested in the topic from glancing at this article. Odd language, such as "two nonmoving assemblies which, if things go wrong, could... collide," probably means that there might be difficulty during assembly. (The author in a private communication has indicated that the paper was published as a theoretical supplement to the talk which he presented at the symposium. Thus it was not intended to be self-sufficient to a reader of modest mathematical or strictly engineering background.)

R68-13984 ASQC 836

TOWARD MORE EFFECTIVE DESIGN REVIEWS.

G. E. Neuner (TRW Systems, Redondo Beach, Calif.).

Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967. Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 205–211.

Design review committee selection, preparations for the design review meeting, layout of the meeting room, and conduct of the actual meeting are discussed. Aids for conducting the meeting, the need for a postmeeting critique, and design review reports are also considered; and some solutions are offered for problems that might arise during the conduct of design reviews. It is noted that such reviews are generally held at three points in a project, namely (1) after the selection of the conceptual review, (2) after preliminary design and analysis, and (3) after final designs and development tests have been completed and drawings are ready for release to manufacturing. Reliability personnel are usually given the responsibility for design review activities at all of these stages. M.W.R.

Review: This is intended to be a set of practical hints for conducting successful design reviews, although a justification of design reviews per se is given in the introduction. The paper will be of concern to those who are conducting or are about to conduct formal design reviews, and they would do well to consider the author's suggestions. Obviously one need not accept them all, but the points he raises are good and the proposed solutions are at least illustrative of a good solution. One of the biggest problems dwelt upon is that of the personal feelings of the people involved and what they do or do not do, what they resent or do not resent, as opposed to what someone else might think they ought to do or feel. Such considerations are, of course, especially important in any critical review process within a company.

R68-13985 ASQC 831; 872

Illinois Univ., Urbana. Coordinated Science Lab.

ON THE GENERATION OF DIAGNOSTIC TEST PROCEDURES

Wendell J. Bouknight May 1966 66 p refs

(Contract DA-28-043-AMC-00073(E); Grant NSF GK-36)

(R-292; AD-633594; N66-33293) CFSTI: HC$3.00/MF$0.65

The problem of generating diagnostic test procedures for combinational logic networks is studied and an algorithm developed that generates test procedures in a form ready to use by a test engineer. The method used to select the input vectors of the test sequence is to choose the best inputs that partition the failures of the network into either single member distinguishable failure classes or indistinguishable failure classes that are distinguishable from the rest of the failures of the network. All knowledge about the behavior of the network is derived from the output results of the test procedures. The algorithm simulates the network to derive the procedures on this basis. Author (TAB)

Review: This large and comprehensive paper gives an algorithm for generating test procedures for combinational logic networks which should prove quite useful. As the author points out, this procedure includes consideration of the failure of input diodes, which some other algorithms neglect. Despite its length (43 pages plus appendices) this is an easy paper to read. The explanations are clear and the mathematics, while careful, is not obtrusive. One small criticism is the author's use of many abbreviations unaccompanied by a glossary. He uses the device of giving the full expression the first time, followed by the initials in parentheses. A reader who forgets this first occurrence is faced with a difficult search when he next encounters the abbreviation. (Underlining the first occurrence would have helped—the reader can do this himself.) Unlike many long papers, this one has the very considerable virtue of including a conclusion. The material is summarized, and the methods are compared with those of other authors. The comments on the areas in which further studies need to be made are valuable. The bibliography is adequate.

R68-13986 ASQC 838

RELIABILITY OF SYSTEMS WITH MAJORITAL ELEMENTS.

V. M. Ozernoy

Engineering Cybernetics, no. 3, May/Jun. 1966, p. 314–317. 3 refs.

Probabilities of different failure modes are determined for a system containing three functional logical blocks and a repair organ or majorital element. Operation of the system is described by a Markov chain with absorption, and the procedure presented is considered applicable for the design of complex information processing systems or for diagnosing system breakdown when the values for breakdown and repair time are known for all of the functional blocks. A Chapman–Kolmogorov equation and a stochastic matrix of transition probabilities are used; and the necessary mathematics is detailed. M.W.R.

Review: This short paper contains a very useful conclusion. Since most current cybernetic devices are at least assumed to be both discrete and synchronous, the author's approach to breakdown probability using Markov-chain-descriptions is well justified. The paper is very readable, and the definitions and assumptions are well stated.

R68-13987 ASQC 838; 872
NONLOADED DUPLEXING TAKING SWITCHING TIME INTO ACCOUNT.
Akhmed Omar and Yusef Nasr
Engineering Cybernetics, no. 3, May/Jun. 1966, p. 310–313. 3 refs.

Time required for switching the reserve device which is out of order was studied in a nonloaded duplexing system, assuming that the trouble-free operation time for the device, the switching time, and the repair time were arbitrarily distributed random variables. The distribution of trouble-free operation time was found when both of the system's devices were in a nonoperational state. It was assumed that repair completely restored the properties of the device and that the three time variables remained invariant. Effect of wear and aging due to repair were not considered in these assumptions. Basic equations were evolved, and transforms introduced to solve the resulting integral equation for trouble-free operation time; and an alternate method for determining the distribution function of trouble-free operation is included. A limit theorem is introduced that shows that when repair time is small the distribution function is asymptotic to an exponential distribution. M.W.R.

Review: One hopes that this paper is not intended as an engineering exercise, despite the title of the journal in which it appears. The authors' preoccupation with the mathematics and their complex symbology quite effectively obscure any practical value. In the basic assumptions the authors "discount" the effect of wear and aging due to repair. This forewarns the reader, of course, and most authors must make some simplifications of this type. Most of them do not admit it. Another good point is the consideration of switching time. This is a much-neglected matter, and they do well to include this. With the exception noted above, this is a good paper.

R68-13988 ASQC 831; 782
Joint Publications Research Service, Washington, D. C.
THE VITALITY OF COMPLEX SYSTEMS
B. S. Fleyshman *In its* Tech. Cybernetics, no. 5, 1966 3 Jan. 1967 p 18–31 refs
(N67-14343)

The capacity of a system to actively withstand the harmful effect of the external environment is examined, with both the operating and the protective elements of the system considered. A stochastic statement of the problem is presented, and a two-step solution to it is given. The independent effects of the protective elements are investigated, and formulas for optimizing the protective structure of the system are derived. It was concluded: (1) The harmful effect of the external environment on the system may be neutralized by introducing redundant protective elements. (2) Optimal behavior and structure are found for the environment acting informally on a system filled uniformly with elements. (3) Optimization of the system increases by several orders the number of harmful active environmental agents required for putting the system out of order; conversely, it lowers the number of protective elements required to maintain operation. M.G.J.

Review: In this paper an interesting approach is taken to the system–environment interaction. Some assumptions are made which are not warranted in most practical situations, but seem necessary to keep the scope of this study within bounds. For example, the uniform and symmetrical relationship which the author postulates rarely occurs in man-made systems and almost never in nature; also the "using up" of the destructive C-elements of the environment in a successful attack on the system's own elements is an oversimplification in some cases (but not, for example, in chemical reactions). The general approach of the paper is philosophical in nature, and might apply equally, for example, to the defense mechanisms of blood reacting against a biological invader, and to the effect of corrosion on metallic devices. The assumption that the environment is actively hostile (aware?) which is made at the bottom of page 21 limits the applications. With the above comments and limitations in mind, this is a very fine paper. Within the framework of the assumptions the author has made, the conclusions are very useful. This approach (protective elements) is as old as the history of armor, but has not often been so nicely analyzed.

R68-13993 ASQC 835; 838
COMMAND-AND-CONTROL SYSTEM MEMORY RELIABILITY.
Herbert G. Jacks (General Precision, Inc., Librascope Group, Glendale, Calif.).
(Institute of Electrical and Electronics Engineers, Aerospace and Electronic Systems Convention, Washington, D. C., Oct. 3–5, 1966, Paper.) IEEE Transactions on Aerospace and Electronics Systems, Supplement, vol. AES-2, Nov. 1966, p. 357–366. 12 refs.
(A67-20685)

The paper demonstrates that reliability of static and rotating magnetic memories applicable to command and control systems can be predicted with sufficient accuracy to be of some value in making system design decisions, using logical extensions of prediction methods in existing reliability handbooks. It is shown that fixed-head rotating magnetic memories are the most reliable large-scale, random-access memories now available, based on MTBF and volume of data stored. It is also noted that modular arrangements of static memory modules can be used to achieve high system memory reliability. Author (IAA)

Review: This is a good paper, not because it is sophisticated or because the results are considered very accurate, but because it shows the kinds of decisions a design/reliability engineer must make in the face of hopelessly inadequate data, e.g., the conflict between (a) risk of program failure and (b) desire for state-of-the-art advancement. There was no need for sophisticated mathematics (and none was used) because the uncertainties in the data far outweighed any differences that alternate mathematical models might have produced. Thus the major value of this paper at this point in time is that it can show theorists the kinds of problems with which engineers often have to deal, it can show the novice what life is often like in the reliability field, and it can help make other practising engineers more unashamed of the "quick and dirty" analyses they must perform in order to get their jobs done.

Thus reading (as opposed to studying) this paper is recommended for almost everyone in the reliability field from novice to high-powered theorist.

R68-13998 ASQC 830; 844
Rolls-Royce, Ltd., Derby (England).
CYCLIC TESTING FOR LIFE PREDICTION
D. McLean London, Tech. Editing and Reprod. Ltd., [1966], p 309–326 Presented at the 27th Mtg. of the Propulsion and Energetics Panel of AGARD, Paris, 4–7 Apr. 1966

Shafts, casings, and disks used in gas turbine engine design are considered in terms of their life expectancy; and it is noted that the aero gas turbine is designed to operate to the maximum permissible stress levels. Weight and cost factors make it impractical to account for all of the unknown factors. Components must, therefore, be submitted to cyclic testing on rigs that simulate environment and stresses expected for the actual engine. Minor component failures are corrected during cyclic testing until the optimum design for such components has been obtained. A torsional fatigue test rig as well as 1000 hp vertical cyclic spinning rig are shown; and several photographs illustrate testing procedure and failures that have occurred. M.W.R.

Review: This is a qualitative paper on fatigue testing for jet engine design. Emphasis is placed on design for finite life rather than for no fatigue failure. An important aspect of this paper is its emphasis on not being able to calculate many things about the stresses and crack propagation in parts; therefore experimental evaluation is essential. It is easy for newer design engineers to get the impression from textbooks and some articles that they can calculate the things they need to know. While it is true that they can calculate some of them, many of the answers are ball-park only, and some do not come even that close. The one sentence "Not all components can be designed to the limits of their material capability; if they could it would infer that every element of every component were operated at the time at its strength limits" is easily misunderstood. A material does not have a single strength, but many kinds of strength, one for each failure mode. For example, if the material were operated near its fatigue strength, it would obviously not be operated near its tensile strength. Also, stress corrosion fatigue could be important and have a different kind of strength. So it is not clear what the author means in this context (but the statement is not essential to the paper). This paper is a good one; it is relatively free of technical jargon, and can be understood by those not directly concerned with this kind of test. Therefore it can benefit reliability and design engineers who wish to know more about the problems of reliability versus fatigue.

R68-13999 ASQC 833
THE F-111 LOGIC—FAMILIAR MATERIALS: PROVEN PROCESSES.
Harry I. McHenry and Rupert E. Key (General Dynamics Corp., Fort Worth Div., Fort Worth, Tex.).
Metal Progress, vol. 93, Mar. 1968, p. 62–68
(A68-28968)

Brief survey of some of the alloys, methods of fabrication, and corrosion control techniques used in the manufacture of the F-111. Each of the three treatments needed to ensure proper corrosion control is elucidated, and the etching process employed in the production of aluminum wing skins is described. Mention is made of plans to electron-beam weld the wing-sweep assembly. IAA

Review: This article provides a good example of the use of mundane materials and processes in the construction of flight hardware. It describes how aluminum alloys are utilized as the primary metal for the fabrication of the F-111. The reasons for selecting these particular alloys and how they were processed and finally formed into the desired configurations are explained. Even though the F-111 can fly faster than Mach 2, the engineers shied away from the use of exotic materials, thereby reducing their treating and fabrication problems. This article will be of interest to design engineers working in areas associated with flight hardware, especially those responsible for the selection of materials. Though terse, the article does demonstrate that it is not always necessary to select the more exotic materials for high-speed flight hardware and many times the tried and proven aluminum alloys, with steels in areas of stress concentration, can be used to advantage, from the standpoints of both cost and weight.

R68-14000 ASQC 830; 720
WELDING THE CRITICAL SPACECRAFT STRUCTURES.
J. Russell Harrison (North American Rockwell Corp., Space Div., Downey, Calif.)
Metal Progress, vol. 93, Mar. 1968, p. 89–94
(A68-28970)

Discussion of the advances made in welding technology used in the construction of the Apollo spacecraft. The use of closed-circuit TV in difficult welding operations is described, and several typical problems encountered in welding the heat shield are analyzed. Methods discovered for reducing the extent of porosity and oxide inclusions in aluminum welds are also presented. IAA

Review: This article will be of interest to production engineers and others concerned with process control in "hard to reach places". It delineates briefly how closed-circuit television was used to control welding of the inner panel joints in the Apollo heat-shield subassembly. It will also be of interest to welding engineers in that it describes some of the welding processes, problems, and their solutions that were encountered in welding some of the critical sections (which were fabricated from materials which were difficult to weld) in the Apollo spacecraft. Some of these problems and their solutions will, no doubt, be of interest to engineers attempting to weld similar materials.

R68-14005 ASQC 833
Hamilton Standard Div., United Aircraft Corp., Broad Brook, Conn. Electronics Dept.
HIGH RELIABILITY MICROCIRCUIT MODULES Interim Report, 1 Jun. 1964–31 Jan. 1966
A. R. Riben and R. E. Antalik Ft. Monmouth, N. J., Army Electron. Command, Aug. 1966 89 p refs
(Contract DA-28-043-AMC-00131(E))
(HSER-3149; ECOM-00131-1; AD-637819; N67-10327) CFSTI: HC $3.00/MF $0.65

Reliability of the Hamilton Standard MicroCircuit Module was studied. MicroCircuit Modules containing only transistors, containing transistors and thin film resistors and capacitors and containing functioning circuits (both hybrid and monolithic circuits) were studied. The tests consisted of high temperature storage, thermal cycling and mechanical environmental stress. The results of these tests were compared to the results of similar tests on identical transistors (fabricated in the same diffusion run) packaged in TO-18 cans. The study showed that the microcircuit module packaging scheme is as reliable as the TO-18 can. More specifically, it was found that the failure rate for transistors packaged in the microcircuit module and stored at 150C was 0.028%/1000 hours. The effect of the formation of gold-aluminum intermetallic compounds at the junction of gold leads and aluminum contact films is discussed. It is shown that proper process control can reduce but not eliminate this effect. This study has shown that highly reliable hybrid and monolithic circuits can be packaged in the

Hamilton Standard MicroCircuit Module, offering substantial weight and volume reduction for complex electronic systems. Author (TAB)

Review: These "microcircuit" modules are reminiscent of the ones that RCA was investigating for the Signal Corps. Apparently only one or at most a few conventional elements are put on each wafer, so that each whole can contains only one circuit. At the time of writing this report, after almost a two-year contract, only sample quantities had been made and the manufacturing techniques were still in the process of drastic improvement. It is doubtful that either reliability engineers or design engineers will find this particular report of much value. It is possible that when the final report is issued, design engineers will be interested in these devices. However, for military or aerospace applications one suspects that their size (roughly, a 0.4-inch cube can contains one circuit) will be against them.

R68-14007 ASQC 830; 612; 882
GENERATOR SET AVAILABILITY.
Glen E. Bratzler and Thomas R. McMurray (Bechtel Corp., San Francisco, Calif.).
Power Engineering, vol. 71, Nov. 1967, p. 51–54.

Estimates for maintenance and spare parts requirements for a power plant can be made by using Monte Carlo techniques to simulate random equipment failures. The resulting random pattern of failures and repair times can be used to determine prime mover and power plant availability. Operation and maintenance schedules were established for a nine-unit diesel plant and for a five-unit gas-turbine plant, and a summary of this availability study is tabulated. M.W.R.

Review: This paper is obviously designed for engineers who have little statistical sophistication. If they read it loosely for just an idea of what was done, the paper will be satisfactory; but if they are concerned about the details of the Monte Carlo testing—at best the paper will be not clear, at worst it will be misleading. For example, the Weibull distribution is presumed for times to failure but nothing is mentioned about the distribution of times to repair. Only one parameter is given for the Weibull distributions and the repair time distributions, viz., the mean, but another parameter needs to be given in order to characterize a Weibull distribution. Presumably after an unscheduled maintenance action the equipment is returned to the same state that an unfailed equipment would have been in at the same time. The final availabilities differ only by make that kind of distinction requires at least 10^4 trials. It is very doubtful from what is said in the text that anywhere near that many trials were made. It is possible that the decision can be made on information generated by the analyses other than just availability but, if so, that should have been more clearly stated. In short, this paper can give other engineers a very rough idea of what they might do in using a Monte Carlo technique for analysis, but it will give them no idea of the difficulties and statistical problems involved in interpreting the results. In a private communication the authors have indicated that the repair time distribution was Weibull also, that four Monte Carlo trials were used, and that an extensive simulation program produced essentially the same answers.

R68-14008 ASQC 830; 090; 844
Bell Aerosystems Co., Buffalo, N. Y. Structural Systems Dept.
UNRESOLVED PROBLEMS IN BRITTLE MATERIAL DESIGN—A CRITICAL LITERATURE REVIEW
W. H. Dukes Paris AGARD May 1966 28 p refs Sponsored by AGARD *Its* AGARD Advisory Rept.-2
(AGARD-AR-2; N67-29477) CFSTI: HC$3.00/MF$0.65

As an initial step in a program to appropriately refine design procedures and techniques for brittle materials, a literature survey was undertaken to review the state-of-the-art and to indicate the more important unresolved problems. Emphasis is placed on design technology specifically to meet the needs of the structural designer. Areas where significant changes are required to accept brittle materials are defined as fracture theory, statistical theory, stress analysis, test methods, and design criteria. Each is discussed in detail. The bibliography is included. M.G.J.

Review: This report was published in May 1966 and apparently reviews the relevant literature up through very early 1966 (although the author gives no date, there are two references in early 1966 and several in 1965). The report can be read easily by anyone with elementary mechanical design knowledge. There is no objectionable jargon. The report is directed toward design techniques and design problems as opposed to data on the physical properties of materials. In brittle materials, testing of the strength is an important part of the design aspect since the tensile strength is so difficult to measure due to the lack of local plastic yielding. Therefore the uncertainties in knowing what the stresses are and being able to screen out unsatisfactory batches of material are very important design considerations. It would have been nice if this article had solved some of the problems, but the title "Unresolved problems..." eliminates that possibility. This report will be of value to design engineers who must use brittle materials and therefore are forced to become familiar with these problems, and to those who are doing applied research in the field or who wish to become involved in it. If brittle materials are to become widely used, then it must be easy for the designer to use them and this requires, of course, that many of these unresolved problems be solved.

84 METHODS OF RELIABILITY ANALYSIS

R68-13973 ASQC 844; 851
PREDICTING RESISTANCE SHIFT IN METAL FILM RESISTORS.
Burton Cushner and Andrew C. Irvine (IRC, Inc., Philadelphia, Pa.).
Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967.
Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 27–36.

Predicting resistance shift was studied in glass encapsulated metal film resistors, and capability of this type resistor to operate for long periods of time at twice the rated power of 1/8 watt was investigated by constructing an experimental design with its main cell operating at 1/4 watt and 125° C. Each of 3,749 resistors were tested for 10,000 hr; and readings were made at 25° C at 250, 500, 750, 1000, 4000, 6000, 8000, and 10,000 hr. A maximum estimated failure rate of .003%/1000 hr at 60% confidence was found; and a larger sample size and number of hours are considered to result in a better performance. Resistance shift due to stress is discussed; as is the development of a mathematical model that explains change in resistance as a function of time, absolute temperature, quantity of electricity, and voltage gradient. Use of the model is shown by including several examples. M.W.R.

Review: This is a report of a fairly straightforward test program. Several engineering decisions had to be made in the course of the test and, at least insofar as reported, they appear reasonable. A formula for resistance change versus time, dissipated power, and ambient temperature was derived from the experiments. The

limitations of the formula are not listed sufficiently. For example, above a certain power and temperature, catastrophic failure (so-called) occurs after a short time, whereas the formula would predict continued negative drift. A further difficulty with the formula is expressed in Figure 7 and at the top of page 35 wherein it is stated "In every case the predicted change was greater than the actual test readings." In most methods of fitting the data, the algebraic sum of the residuals would be close to zero; thus there would seem to be some bias in this equation. (In a private communication the author has stated that "... the comparisons...were external to the matrix data... The fact that the results are less than predicted...represents processing refinements.") No indication of the uncertainty in the estimated value is given, whereas this too would have been a help. However, it is stated that the standard deviation is highly correlated with the mean value. There are a few editorial problems, the most disturbing of which is: page 31 should be page 34 and the successive page numbers should each have one subtracted from them until the page numbered 34 is reached; some of the numbers in the text and the tables do not agree. No justification was given for some of the numbers being determined by the regression and others being determined by some other means before the regression analysis. Novice design engineers should be cautioned that an article such as this does not replace a specification on the parts. Before counting on a particular resistor to do a particular kind of thing in a high-reliability application, there should be some formal contractual arrangement with the manufacturer. All in all, the paper is reasonable and shows the kinds of things that are useful to do in a test.

R68-13990 ASQC 844

HOW TO USE FAILURE ANALYSIS TO IMPROVE SEMICONDUCTOR RELIABILITY.

Hrand M. Muncheryan (General Precision Systems, Inc., Librascope Div., Glendale, Calif.).

The Electronic Engineer, May 1968, p. 49–54.

Preproduction, life, physical, and nondestructive tests to determine failures in microelectronic devices are considered in relation to improving component reliability. Thermal, mechanical, burn-in, and leak tests are described; as are nondestructive methods using X-ray radiography, liquid-crystal profile imaging, and infrared scanning. Typical procedures for making failure analysis are presented, including uncapping, visual examination, and cross sectioning. Correlation between defects and failures are discussed, and the need for verifying failure mechanisms is stressed. Metallographic examination is considered the first step in failure analysis, and this is to be followed by functional electrical tests. Results of these should be combined to develop screening tests for both quality control and final inspection. It is noted that human errors play an important role in device failure; and, because a large percentage of microcircuit failures are due to bonding problems, mention is made of various materials that are being investigated by semiconductor manufacturers. M.W.R.

Review: This paper is a very general summary of the kinds of tests that manufacturers use to improve their semiconductor reliability. While new reliability engineers and component specialists may profit from reading this report, manufacturers of semiconductors will consider the information well known. Most of the information is rather bland and the reader does not get any idea of the trials and tribulations involved in actually having to deal with the recalcitrant devices. The only kinds of life tests mentioned are constant-stress tests. Many people use step-stress tests for these devices. The first paragraph which says that nothing can be done to improve the inherent quality of a device once it is manufactured is true, but can be misleading. While one cannot inspect reliability into a device, one can inspect unreliability out of a group of devices and this is called screening. It is, of course, not completely effective but does nevertheless improve the reliability of the group. Perhaps the most illuminating comment and one which agrees with the experience of many others is that "... the majority if not all of device failures are due to careless human errors." These take place anywhere from the device production line up through testing of the completed equipment. In a private communication the author has stated that his original paper conveyed much more information than the published article. (This is not an uncommon plaint about the trade magazines.)

R68-13992 ASQC 844

HEADING OFF AIRCRAFT FATIGUE.

John A. King

Space/Aeronautics, vol. 49, Feb. 1968, p. 79–86. 10 refs. (A68-21954)

Study of the possibility of preventing fatigue through improved design. This can only be achieved by nailing down and correlating the basic fatigue mechanisms. The complexity of this task has several origins: (1) cyclic acoustic, mechanical, and thermal loading have interrelated fatigue effects, even though they may have different causes; (2) low-cycle and high-cycle mechanical loading may have synergistic effects that have not been fully defined; (3) laboratory tests of materials and components of structural systems cannot simulate real-life loading conditions with randomly variable frequencies and magnitudes; (4) insufficient theoretical comprehension of the fatigue-failure mechanism exists to permit correlation of laboratory data with real-life structural loading situations; and (5) inadequate data are available to adequately predict the ground-air-ground loading cycle of advanced aircraft flight paths, particularly for the high-altitude cruising portion of the cycle. IAA

Review: This article will be of general interest to engineer-designers concerned with fluctuating loads and associated fatigue stresses, particularly those encountered in aircraft and other flight hardware. The author presents the basic problems in forecasting fatigue stresses and some of the efforts which are currently being carried on in an attempt to improve the analytical methods for modeling these fatigue stresses. He is obviously well-versed in this area and gives a good generic summary-type presentation. Particular attention is called to the first reference in the bibliography, the review paper by H. F. Hardrath. This paper is recommended for persons interested in delving deeper into the research which has been conducted in this area during the last several years. There seem to be several misprints in the two equations on page 80. In column 1, the effective dynamic stress designated by S in the test is shown as $\overline{S}$ in the equation. This is a minor inconsistency. The second equation in column 2, shows the term $S_a^{1/2}$; this probably should have been written as $S\sqrt{a}$. The text under the figure at the top of page 81 states that the thermal loading is represented by a dashed line in the figure above. In printing, this seems to be represented by a solid white line instead of a dashed line. This is an interesting paper and is recommended as an introduction to the general problems encountered in aircraft fatigue stresses.

R68-13994 ASQC 844

SOME RELIABILITY/EFFICIENCY ASPECTS OF LOW INPUT VOLTAGE INVERSION/CONVERSION FROM RADIOISOTOPIC THERMOELECTRIC GENERATOR POWER SOURCES.

Edward R. Pasciutti (NASA, Goddard Space Flight Center, Greenbelt, Md.).

(Institute of Electrical and Electronics Engineers, Aerospace and Electronic Systems Convention, Washington, D. C., Oct. 3–5, 1966, Paper.) IEEE Transactions on Aerospace and Electronic Systems,

Supplement, vol. AES-2, Nov. 1966, p. 458–465. 8 refs. NASA-Supported Research.
(A67-20694)

The transistor component failure possibilities due to voltage and power stress conditions existent in low input voltage inverters when energized by a radioisotopic thermoelectric generator source (RTG) have been investigated in depth. Circuitwise, it is shown that a properly designed current feedback driven inverter is inherently failsafe with respect to output overload when supplied from a power limited source. An RTG no-load overvoltage protection technique recently developed and described herein offers low dissipation external to the RTG source output power terminals. This is important for satellite or spacecraft applications, because it enables a reduction of radiator requirements needed for heat rejection. Author (IAA)

Review: This paper treats a particular circuit in some detail and takes care not to make too many simpleminded assumptions about the detailed behavior of the components and the signals. This is the kind of reliability analysis which is best exemplified by the phrase, "infinite attention to detail" and is an essential part of good engineering for long life. It is not the kind of reliability engineering which estimates the time-to-failure of the system. This paper is worthwhile noting, especially for those who feel that reliability is merely a numbers game. As far as power supply design is concerned, the paper is, naturally, limited specifically to the explicit system discussed rather than being applicable to power supplies in general.

R68-13995 ASQC 844
PREVENTION OF CORROSION FAILURES IN BRIDGE MEMBERS.
Ben Balala (Dept. of Public Works, Bay Toll Crossings Div., San Francisco, Calif.).
1966 Golden Gate Conference, San Francisco, Calif., Nov. 10–12, 1966, Paper. Metals Park, Ohio, American Society for Metals, [1966], 13 p.
(ASM Technical Report GG6-1.3) Members, $1.50; nonmembers, $3.00.

Solutions to problems involved in corrosion failures in bridge members are discussed, along with recent innovations used to minimize corrosion. Following proper design and construction, continuous maintenance is considered to offer the best preventative. Design codes used in heavy civil engineering are reviewed, and the need for their continuous revision is stressed. Reinforced concrete, prestressed concrete, and structural steel materials are considered, and some typical failures in bridge members are noted. M.W.R.

Review: While a paper on the prevention of corrosion failures in bridges does not at first glance seem appropriate for aerospace engineers, there is much they can learn from it. The same kind of attention to details so necessary in aerospace reliability is also necessary in the design and physical construction of the bridges. Workmanship must be carefully monitored and things which are hard for workmen to do correctly should be avoided. Another mentioned point is that people tend to brag about their "good designs", but not to write an article later about how the structure failed prematurely. Since the article applies to many structures besides bridges, some of the points are of direct concern to those who must build launching pads, etc. This is a general paper appropriate for a mixed audience and thus can be read easily by managers and others who are not directly knowledgeable with the jargon of civil engineers. The paper also shows that reliability has been going on for many years under other names in various fields. The same kinds of failures are referenced by the author in two books published some forty (40) years apart; this is reminiscent of the Navy's complaint that many of the types of failure in their planes are the same now as they were in the early days of aircraft. (The author is somewhat more sanguine about the adequacy of Building Codes than are many users.)

R68-13996 ASQC 844
THE PREVENTION OF METAL PART FAILURE BY THE USE OF PROTECTIVE COATINGS.
L. M. Cowden (Union Carbide Corp., Linde Div., Indianapolis, Ind.).
1966 Golden Gate Conference, San Francisco, Calif., Nov. 10–12, 1966, Paper. Metals Park, Ohio, American Society for Metals, [1966], 12 p.
(ASM Technical Report-GG6-1.10) Members, $1.50; nonmembers, $3.00.

Coatings on jet engine turbine and compressor blades and on wire drawing capstans are considered, and attention is given to the development of a pit-free, pore-free tungsten carbide–cobalt coating. Flame-plated chrome oxide coatings for wire steel, copper, Inconel, aluminum, molybdenum, tungsten, and copper/brass coated steel are mentioned. Applications in which coatings are used to prevent failure are noted, including tungsten applied to the contact area in reed contacts and switches and on components used in manufacturing textile yarn. M.W.R.

Review: Even though the author is unmistakably enthusiastic about his company's products, enough of the failures and partial successes are described to give a realistic idea to others of the difficulties involved in trying to improve the life of parts. That such improvements are possible should not be overlooked by design engineers, although no mention is made in the paper of the relative cost. It is implied, however, that the increased cost of the coating is negligible compared to the increase in service life. Papers such as this provide a valuable service, especially when they show that the road to success is not the smooth one often portrayed in journal articles and conference lectures. They enable other engineers to evaluate more accurately their own progress toward their goals. As is common in metallurgy (and has been for many years) the so-called "physics of failure" approach is used to find out how and why parts fail. (This kind of metallurgical analysis may have been the prototype for the burgeoning of "physics of failure" in the reliability field.) Those design engineers who are involved with metal parts which wear can profit from the reading of this paper.

R68-13997 ASQC 844
CASE HISTORIES OF FAILURES IN TITANIUM AND SUPER-ALLOY FORGINGS.
A. L. Rustay and J. E. Coyne (Wyman-Gordon Co., Worcester, Mass.).
1966 Golden Gate Conference, San Francisco, Calif., Nov. 10–12, 1966, Paper. Metals Park, Ohio, American Society for Metals, [1966], 15 p.
(ASM Technical Report GG6-1.5) Members, $1.50; nonmembers, $3.00.

Selected case histories of failures of titanium and nickel-base superalloy forgings were analyzed. In using Ti–13V–11Cr–3Al, the need for careful machining was indicated in one case and the interdependence of thermal and mechanical processing when making forgings was illustrated in another case. When four heats of Waspaloy were forged into turbine wheels, inspection after heat treatment revealed a considerable number of cracked forgings from one of the heats; and electron microscopy indicated a distinct difference in the grain boundary regions between good and bad parts. Grain boundary depletion was found to affect forgeability and mechanical properties of A-286, Inco 901, and Inco 718; and it was concluded that the undesirable grain boundary condition was initiated during the conversion of ingot to bar. Two 8,000 lb nozzle forgings of Hastelloy X cracked. One piece that was heated to

about 2200°F, equalized immediately after forging, and air cooled; it was decided that the air cooling created a temperature gradient that induced stresses to produce the crack. The second piece was cooled at the rate of about 300°F per hour from 2150°F; and mathematical analysis indicated that when the surface was 1200°F the center of the mass was about 2000°F. Microexamination revealed a grain boundary film, which was corrected through processing. M.W.R.

Review: As the name implies, this paper deals with three cases of failure, and provides metallurgists and mechanical engineers with information which shows that we are a long way from being able to predict what will happen with materials that we use. In some cases, the people should have known better, in others the extrapolations from past practice were insufficient. Again, attention to detail is important for high reliability. Often it happens that people in one plant are not familiar with the experience of people in other plants. With the much more frequent use of materials near their limits, and with materials which are much less forgiving of errors in treatment and environment, some means is necessary to codify rapidly the experience of those who are working with metals. Papers such as this are one way, but more systematic efforts including survey-review papers and books need to be investigated if the practical workers in the field are to be able to make use efficiently of new materials and techniques. This paper is appropriate reading for design engineers, practicing metallurgists, and shop people who are concerned with this kind of material.

R68-14001 ASQC 844; 815
DESIGN ANALYSIS PROCEDURE FOR FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS (FMECA).
Aerospace Recommended Practice, New York, N. Y., Society of Automotive Engineers, Inc., 1967, 12 p.
(SAE-Paper-675294)

Purpose and procedure for Failure Mode Effects and Criticality Analysis (FMECA) are outlined. The FMECA, recommended as an integral part of the early design process of system functional assembly, should be periodically updated to reflect design changes so that it can be used in design reviews, inspections, and certifications. In effect, FMECA is a design evaluation procedure that documents potential failures in system or component design, determines effect of each failure on system operation, identifies failures critical to operational success or personnel safety, and ranks each potential failure according to the combined influence of failure effect severity and probability of occurrence. Detailed analyses procedures are included, as are the method and format for criticality number calculation. M.W.R.

Review: Failure mode effects and criticality analysis (FMECA) is a good practical concept, and when judiciously applied is one of the most important and productive tasks of a complete reliability engineering program. It, or the less extensive failure mode and effects analysis (FMEA), has essentially become routine practice in most hardware programs. It is thus fitting and proper that standards for its implementation such as these should evolve from this experience. Whereas many programs require specific features to be included in the FMECA or FMEA, this document does provide good guidelines for implementation, even for engineers without previous knowledge of the concept. The text is quite ambitious when it refers to FMECA as a "... procedure which documents all conceivable potential failures in a system or component design ...". With complex systems there is a practical level of detail to which it can be conducted, as things can quickly get out of hand if too much detail is included. Some good rationale on selecting a practical level of detail is presented in the paper covered by R68-13854. Also, the FMECA does not have to be limited to individual component failures as suggested in the document. Certain failures which separately do not jeopardize system operation may, when occurring jointly with others, become critical to system operation even though the probability of their joint occurrence is small. Generally, in performing the analysis the engineer must select the depth and scope which best suits his purpose. The persons and organizations responsible for producing this document are to be commended for their effort. Other descriptions of FMECA are contained in the papers covered by R67-12939, R67-12940, and R68-13665.

R68-14002 ASQC 844; 612
Westinghouse Electric Corp., Baltimore, Md. Product Support and Equipment Dept.
PROJECT FAATE, PHASE 1 FINAL REPORT
1 Oct. 1967 170 p refs Reprint
(Contract N00163-66-C-0413)
(TP-339; AD-662190; N68-14982)

The report consists of three separate parts: Part I contains background information and summary of the overall program; Part II presents a detailed account of a controlled experiment that was performed to verify the BFIC concept; and Part III exhibits the development of a computer approach used to generate Fault Isolation routines, and the results obtained. TAB

Review: Anyone interested in developing practical, improved fault isolation procedures should become aware of the study described in this report. The key result is the demonstration of the feasibility of developing and beneficially using optimized test procedures. For manual testing, these procedures are specified in the form of a Binary Fault Isolation Chart (BFIC) for each equipment. It is clear from the description that similar instructions can be programmed and executed by automatic test equipment. The BFIC's or the automatic test equipment programs are developed from fault libraries. A computer program, Selected Tests Optimization Program (STOP), is described (and listed) for doing this, and the development of this program is a unique feature of this study. The procedures described for developing the fault library are essentially the same as those reported by others (see, for example, the paper covered by R67-13263). A special study for the manual testing method using BFIC's clearly demonstrated that the approach is superior to the more conventional trial-and-error approach. It was also interesting that the costs of the added effort to develop the BFIC's can be amortized with relatively few items to be maintained. Whereas the emphasis in this study was on analog circuits, the basic approach will be adaptable to digital circuits and other types of equipment. The applications demonstrated involved relatively simple circuits having essentially a single function to perform. More complex situations can obviously be treated by these procedures. Very complex circuits having many possible functional capabilities, such as many-terminal integrated circuits which can be employed in many different input-output configurations will require more powerful techniques. Such techniques are yet to be fully developed; research efforts oriented toward developing fault isolation procedures for complex devices are described in the articles covered by R66-12856 and R68-13902.

R68-14003 ASQC 844; 770
National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.
EFFECTIVENESS OF ENVIRONMENT-SIMULATION TESTING FOR SPACECRAFT
John C. Nev and A. R. Timmins Washington, NASA, Jun. 1967 13 p refs
(NASA-TN-D-4009; N67-27222) CFSTI: HC$3.00/MF$0.65

The philosophy and purpose of ground simulation tests for unmanned spacecraft, as used at the Goddard Space Flight

Center, is reviewed. Laboratory test results are presented from 16 prototype and 48 flight spacecraft. The summarized results show a four-to-one ratio in problems per spacecraft for prototype compared to flight models, and for both models the simulated space test has revealed the largest number of problems. A comparison of the number of space problems with test problems on the same spacecraft shows no correlation and shows that 100% trouble-free operation was not obtained on any spacecraft. Data from simulated space testing of 270 experiments for an observatory program show an exponential relationship of malfunctions with time. The curve can be used to estimate the number of problems that will be detected by varying the test time, but cannot be extrapolated to long-term (days) testing. The data from the systems test of a complete observatory under simulated space conditions show failures occurring after 12 days of testing and verify the need for long-term systems tests. Author

Review: This brief report will be of interest to a wide audience including top-level managers, system program managers, reliability managers, test managers, and reliability analysts. It is well-written and presents some very interesting summary data from experiences in spacecraft testing. The following comments are presented without any intent of detracting from the value of the report. What the presentation mainly illustrates is that environmental testing at the systems level is very beneficial in detecting and correcting deficiencies in design and fabrication. A more thorough assessment of effectiveness could involve comparing the benefits of extensive testing versus limited testing, extensive simulation of environments versus testing in more benign environments, and systems testing versus component and subsystems testing. There was some consideration of the latter; however, the data presented were not sufficient to permit any firm conclusions to be drawn as to which is more beneficial. The general preference for systems testing would no doubt be substantiated with more data. The ratio of the number of problems per spacecraft for prototype model testing to the number for flight model testing certainly indicates the benefit of prototype model testing. The ratio is possibly influenced to some degree by the relative severity of test conditions for the two test applications; i.e., had the severity of the conditions been equivalent, the ratio might have been smaller but would probably still be significantly greater than unity. Whereas the paper does not present conclusive evidence about the total effectiveness of environmental testing, it should serve to erase many doubts concerning its benefits.

R68-14004 ASQC 844

ASPECTS OF LUBRICATION AFFECTING LIFE OF ROLLING BEARINGS.

J. C. Bell and J. W. Kannel (Battelle Memorial Institute, Columbus, Ohio).

(National Metal Congress, Chicago, Ill., Oct. 31, 1966, Paper.) Metals Engineering Quarterly, vol. 7, Feb. 1967, p. 28–35. 26 refs.

Lubricant pressures and bearing stresses they induce are considered in relation to the life of rolling bearings. Theoretical pressure patterns between lubricated rolling cylinders are shown, and the measurement of pressures between lubricated rolling disks is discussed. Comparison is made of the static and dynamic stresses in cylindrical disks for various loadings. Pressures between lubricated rolling disks differ somewhat from Hertzian pressures between disks in static contact, but these differences generally decrease as the load increases. While the subsurface shearing stresses occurring during lubricated contact differ from those during dry contact, the maximum levels reached do not differ greatly. Difference in calculated shearing stress for mineral oil and polyphenyl ether lubricants was small. While the type of lubricant used in rolling contact has been shown to be capable of affecting bearing life, the variations in stresses induced by normal pressures do not appear to be large enough to explain observed differences in life. Theoretical film thickness between rolling cylinders is discussed, and the X-ray technique for measuring film thickness is included. Thickness of lubricant film between rolling-contact elements is a definite factor influencing life. M.W.R.

Review: After reading articles on the life of antifriction bearings, with regard to fatigue-lubrication failures, it often seems that the more we learn the less we know. This is typical of many areas where quick-and-dirty engineering formulas and relatively few data were all that were available for a long time. The authors present some mathematical and phenomenological models and discuss the difficulties associated with them—the models do not explain the full range of observations which are made on the effect of lubrication on fatigue life. It is fashionable in reliability circles to call this kind of an investigation "physics-of-failure" or "reliability physics", but regardless of the names, it is thorough research such as this that the lives of the components we use can be improved. This paper uses a minimum of technical jargon and thus can be understood by those mechanical, metallurgical, and lubrication engineers who are interested in this field. It is noteworthy that this kind of research receives support from many areas.

R68-14006 ASQC 844

SKF Industries, Inc., King of Prussia, Pa. Research Lab.

ROLLING CONTACT FAILURE CONTROL THROUGH LUBRICATION Special Research Report

T. E. Tallian 19 Sep. 1966 118 p refs

(Contracts Nonr-4433(00); Nonr-4895(00); NOw-61-0716-c; NOw-64-0428-c; NOw-65-0182-f; et al)

(AL66Q028; AD-641189; N67-25339) CFSTI: HC $3.00/MF $0.65

Lubrication in rolling contacts serves primarily to control failure and must be engineered for that purpose. Four classes of failure are defined in rolling contact mechanisms: wear (mild wear and smearing, involving metal transfer); plastic flow (cold or due to overheating); fatigue (spalling and surface distress); and bulk failure modes occurring away from the contact areas. Generalized "stress fields" leading to rolling contact failure are defined as mechanical, thermal and (possibly) chemical "stresses". The severity parameters of these stress fields are developed and illustrated by typical relationships based on Hertzian assumptions and are progressively refined through the stepwise inclusion of tractive surface forces, plasticity, elastohydrodynamics, and of effects of surface microtopography (boundary lubrication) and material inhomogeneities. Effects of lubrication on these severity parameters are identified. Experimental and theoretical findings on the detailed failure mechanism are used to derive failure criteria, including lubrication effects, for each failure mode. Methods are presented on this basis for the control of failures. Author

Review: This report is a good primer for mechanical engineers and others with similar backgrounds who need to learn the more detailed mechanisms of operation and failure of rolling contact bearings. There is a minimum of jargon; the author does not assume an extensive background in the area; and he develops the subject well. Sixty-three references are cited to aid in further study and to establish some of the points. The report reflects modern thinking on the subject and mentions the areas which are not well understood in addition to those which are. This is not a handbook for the design engineer but will be useful to the bearing specialist or to the mechanical design engineer who, perhaps against his will, is becoming a bearing specialist. This kind of tutorial reporting of research material is essential to the progress of high reliability, and can lead to the more accurate prediction of bearing life. (However, at the moment it seems to serve more as an explanation of why bearing life often cannot be predicted adequately.) In a private

communication the author has stated that some of the important information is only briefly mentioned—so the casual reader must be careful not to miss it, and that some of his points are controversial.

R68-14011 ASQC 844; 612
AN OVERVIEW—RELIABILITY AND THE COMPUTER.
Patrick P. Donnelly (Boeing Co., Houston, Tex.).
Evaluation Engineering, vol. 7, May/Jun. 1968, p. 10.

Mathematical models, Failure Mode and Effect Analysis (FMEA), and Criticality Determination (CD) are considered in terms of reliability prediction by computer programs. Primary function of the mathematical model is to obtain a predicted value of the probability of the system success, while the FMEA identifies component subsystems that are critical to system success. The FMEA provides qualitative results, wheras the CD is quantitative and provides a numerical ranking of hardware items whose failure will adversely affect system success. The computer is considered effective in such reliability determinations because it provides both speed of information retrieval and flexibility to incorporate changes in the overall program when up-to-date information is available. M.W.R.

Review: This is an extremely short overview and will be useful only to the strict novice who has had little experience with computers and who has virtually no idea of what they might or might not do. One important area which was omitted was that of improved subsystem design by being able to check the severity level for each of the elements in a subsystem. In electronics, for example, the voltages, currents, and power can be calculated between any two nodes and programs exist for these. In mechanical engineering there are programs which can calculate the stresses in certain kinds of structures. Thus, the computer helps the engineer pay attention to those many details that are essential for high reliability. The other aspect of computers that is not dwelt upon is that the initiation period tends to be expensive and painful, since the glowing rewards fail to materialize right away and wrong answers are abundant, programs do not run, and the bills mount astronomically. This should not discourage anyone from getting started; it should merely prepare him for the transient trauma which he will experience. When he comes out of it he will be a much wiser person and have a grasp of an extremely useful tool.

R68-14013 ASQC 844
SOLID TANTALUM CAPACITOR FAILURE MECHANISMS—TUTORIAL.
Harry W. Holland (Union Carbide Corp., Electronics Div., Components Dept., Quality Assurance, New York, N. Y.).
Evaluation Engineering, vol. 7, May/Jun. 1968, p. 38, 39, 41.

Product design and manufacturing process are discussed for the solid tantalum capacitor in order to understand its failure mechanisms. Impurities in tantalum capacitors are considered that result in the inability of anodization to produce a continuous Ta_2O_5 layer of uniform thickness, and leakage current is related to the size of the electrical faults that result. Statistical studies of failure are noted, and acceleration and anticipated service life are considered. With knowledge of applicable acceleration factors, it is possible to life test entire lots of capacitors and determine failure rates very quickly. M.W.R.

Review: There are several different kinds of tantalum capacitors; the failure mechanisms for each tend to be somewhat different. It is difficult for the non-specialist to keep these different ones straight, so that articles like this can be a help. There are no references for further study, but the report by the same author covered by R67-13138 goes into some of the production steps and failure mechanisms in more detail. In the testing recommended in the present paper, the series resistance is low, so that transient shorts which might otherwise be self-healing will cause failure. This may not be indicative of actual practice wherein the flicker can cause transient malfunction, but the series resistance may be high enough to avoid a short. The application section of this paper is very short and many points which might be important to design and reliability engineers are passed over quickly—although some good specific points are raised.

R68-14015 ASQC 845
SWEDISH FAILURE RATE DATA BANK.
Birger Olsson (Swedish Military Electronics Lab., Stockholm, Sweden).
Electronic Components, vol. 9, May 1968, p. 555, 556.

A failure rate data bank established in Sweden is concerned primarily with electronic and telecommunication components and provides data for forecasting reliability of complex equipments during the early phases of design and development. Information at the bank is based on data from electronic component field and test data supplied by both manufacturers and users. Data are summarized on failure rate data cards, which are sent to the manufacturer for his approval before their distribution to subscribers. These cards, printed in English, contain data on the component's environmental classification, type approval status, point estimate and 60% upper confidence level failure rates, and type of life distribution. Normalized reliability, application factors, IDEP and M codes, and a diagram of failure rate as a function of temperature and load are also included. A typical failure rate data card is reprinted that indicates reliability of a solid electrolyte fixed tantalum capacitor. M.W.R.

Review: This is an interesting project the Swedish have embarked upon. The summary given in this two-page paper is extremely brief, so that undoubtedly many important details have been omitted. Some points which should be emphasized about this service are the following. 1. Apparently a manufacturer is permitted to approve or reject the data on his parts; thus presumably if he objects, a card is not issued. 2. Both drift and catastrophic failures appear to be considered and the definition of failure is given. 3. There is no indication of the way in which failure rates are determined relative to temperature and "stress". 4. Even though there is much that the forms do not report, and they undoubtedly omit much that many reliability theorists would insist should be there, they appear to be doing the best that they can with the information at hand. Certainly this kind of information is going to be better than nothing, which is approximately the choice an engineer has. Presumably those who are interested can write to the author for more details.

R68-14017 ASQC 844; 830
FACTORS IN FASTENER RELIABILITY.
G. N. Hall and Oliver Breward (Unbrako, Ltd., Conventry, England).
Aircraft Engineering, vol. 39, Mar. 1967, p. 35–37
(A67-24040)

Review of significant factors affecting the reliability of aerospace fasteners. It is pointed out that the mechanical testing, whether tensile, fatigue, stress, rupture, shear, sustained load or torque tension properties, as required, is carried out on every lot of fasteners shipped under an advanced design label and constitutes a fundamental part of the assurance of the performance reliability that aerospace contractors have come to expect. IAA

Review: Fasteners are an essential ingredient in aerospace high reliability and one cannot simply substitute hardware-store nuts and bolts for fasteners of guaranteed high quality even though

they have much in common in terms of appearance and nominal dimensions (members of Congress who are bent on economy drives notwithstanding). This is the kind of paper that provides background information for designers and gives the manufacturer a chance to brag about his wares. A designer, of course, cannot use this paper in lieu of specifications, nor can he assume that every batch of fasteners he gets will have had the superb treatment mentioned here, since mistakes do happen. One of the difficulties with this type of paper, as far as reliability engineers are concerned, is that it deals only with the way management would like to have its plant run and perhaps even feels that the plant is run. It does not deal with the hard-core problems of shipping schedules, incoming material delays, poor inspection, etc. (The paper was undoubtedly not intended to deal with those subjects, but this does not mean that they are unimportant in high reliability.) The paper can give designers and reliability engineers an idea of the kinds of things they should specify and look out for. It can give metallurgical engineers an idea of what is demanded for high reliability.

R68-14018 ASQC 844; 853; 864

RELIABILITY AND FIELD EXPERIENCE OF ELECTRONIC SWITCHING SYSTEMS.

William P. Karas (Stromberg-Carlson Corp., Rochester, N. Y.).
In: Record of the 1967 IEEE Convention, Part 1—Wire and Data Communication, New York, N. Y., Mar. 20–23, 1967. New York, N. Y., IEEE, Inc., 1967, p. 184–193. 4 refs.

Field experience with electronic switching systems for commercial telephone service is compared with design objectives expressed in reliability and maintainability parameters. A feedback system for collecting field performance data was established, reliability analyses were made, and the results obtained were applied to a reliability model for determining the degree to which the design objectives were met. The reliability and maintainability objectives are discussed; and the objectives set with regard to failure permit the determination of required redundancy of common equipment and need for multiple equipment. Attention is given to component parts reliability and failure rates, field experiences, and an electronic register sender used in switching equipment. M.W.R.

Review: The reliability requirements and concepts are different for telephone systems, military equipment, and space missions; this fact should be kept in mind when reading papers on these different subjects. This paper deals with electronic switching systems for commerical telephone service. While the reliability requirements seem high when measured against some military or space experience, it should be remembered that the concept of reliability in telephone systems allows for performance degradation in terms of the quality or availability of a connection. This is not to minimize the problems and progress of the telephone companies (since they are pushing their state-of-the-art as hard as anyone) but to point out that simple transfer of numbers is not possible. This paper gives a general point of view, and can be read easily and understood by those not intimately acquainted with the field. The very simplest of reliability models was used: constant hazard rate; elements are good/bad, the hazard rates for drift and catastrophic failures of subsystems are added, and hazard rate is doubled for each 10°C rise in temperature. Field experience showed that the actual time between malfunctions was considerably longer than the minimum required in the specifications. This article will be of some value to those who wish to get a rough idea of the experience of others for this kind of system. (The use of the term *random failure* to denote catastrophic failures following a Poisson distribution should be discouraged, since any failure whose time of occurrence is not precisely enough known is a random failure.)

R68-14019 ASQC 844; 864

ELECTRONIC RELIABILITY IN THE FIELD.

John A. Lawrence and Trevor F. A. Urben (British Post Office, London, England).
In: Record of the 1967 IEEE Convention, Part 1—Wire and Data Communication, New York, N. Y., Mar. 20–23, 1967. New York, N. Y., IEEE, Inc., 1967, p. 208–224.

Experiences with gold cathode, magnet drum, and ferrite core register translator equipment used in a long distance switching network are reported, and reference is made to the performance of the TXE2 electronic exchange used by the British Post Office system. An electronically controlled reed-relay switching system, TXE2 sets up calls on a one-at-a-time basis; and a single unit can handle up to 2,000 connections. The system built-in checking facilities applied during the setting of each call, an automatic repeat attempt facility incorporated into each register, a crosspoint continuity check of the switch path, and the use of a monitor to print details of all failures. Components, equipment accessibility, fault detection equipment, and reducing the effects of faults are described; and field performance data are included. Fault clearance time, costs, system security, maintenance organization, and records of faults are also included for the TXE2 system. M.W.R.

Review: A large portion of this paper is devoted to describing the way in which three different Register-Translators operate, behave, and are constructed; an electronic office is also described. The discussion of maintenance and reliability is at a quite general level (in contrast to the specific information in the paper by Karas on p. 184–193 in the same volume). This account of British experience is valuable to have, but it is directly comparable only with telephone systems, since space and military installations usually have quite different meanings for reliability. Maintenance, especially for the electronics system, is discussed to some extent. The point has been made elsewhere that the initial hazard rate in such a system is quite high due in large part to the intensive servicing it receives; the effect of this wears off after a while and the hazard rate decreases to a low, acceptable value. The kinds and methods of redundancy, both hardware and software, are mentioned, and the advantages of software redundancy are explained for telephone systems. In short, this paper is suitable for anyone who wants a quite general overview of the British telephone experience on this kind of system.

85 DEMONSTRATION/MEASUREMENT

R68-13980 ASQC 851; 770

PROVING OR IMPROVING RELIABILITY THROUGH TESTING.

Walter E. Miller (Litton Systems, Inc., Data Systems Div., Van Nuys, Calif.): *Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967.* Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 145–153.

Design verification testing as well as tests to demonstrate or improve reliability are discussed in terms of parts, assemblies, and systems; and a chronological sequence of equipment evaluation tests from the research and development phase through actual field usage is tabulated. Failure analysis is considered an integral part of the program in order to establish the dominant failure modes; and mention is made of the various environmental tests and their general purposes. General rules are indicated for system qualification testing, and economic factors involved in testing at each of the levels are discussed. M.W.R.

Review: This is a short tutorial paper and undoubtedly was worth listening to for many in the audience. It does give engineers an idea of what kinds of tests one can run to improve life and reliability, and gives practical ideas on associated problems such as cost. The paper would be useful for doing a similar thing for a casual reader if the Proceedings were readily available to him. Some of the names of the kinds of testing undoubtedly vary among organizations, so they should be taken as typical names rather than exact ones.

R68-13981 ASQC 853; 864

SYSTEM FIELD RELIABILITY—A CASE STUDY.

Albert L. Rosenberg, Jr. (Radio Corp. of America, West Coast Div., Reliability Product Assurance, Van Nuys, Calif.). *Spectrum of Reliability; Proceedings of the Annual West Coast Reliability Symposium, 8th, Beverly Hills, Calif., Feb. 18, 1967.* Symposium sponsored by the Reliability Div., Los Angeles Section, American Society for Quality Control. North Hollywood, Calif., Western Periodicals Co., 1967, p. 155–174.

Analysis of the reliability of a complex operating system is described beginning with the theoretical calculations of reliability performance at the schematic stage and following the procedures step by step until complete overall expected reliability figures are obtained. The method of calculating actual field performance is shown, and performance is indicated over a period of a year and half by graphs of mean time between failure per system and tables containing other pertinent data. Complications involved in calculating system reliability are noted along with the methods used to compare field performance of the four computer systems involved in the overall operating system. Engineering estimates of system reliability were made by quick examination of the reliability of each part, including stress and experience factors; and by comparison of the estimated total of component types with experience in other systems. Data are summarized from the individual site failure reports. M.W.R.

Review: This is a good case history paper and is a valuable one to present at such a Symposium. The sharing of experiences is very worthwhile, especially those that show the kinds of engineering decisions and compromises that are made in the course of any practical task. This kind of paper is sometimes necessary as an antidote to overdoses of high-powered theory. Two kinds of people will find this paper valuable. The first, and perhaps most unlikely, are the theorists, who can now see (a) the kinds of things that people actually do, (b) the problems with which those people are actually faced, and (c) the kinds of data they have to solve them with. This can help them construct more realistic models. (However, constructing currently-realistic models is not the sine qua non of theoretical research.) The other group who can profit from this paper are those who are faced with similar tasks and would wish to read this paper in more detail to see just what it was that the author did and did not do, and how he did it. The novice should be warned that the hazard rate calculations in the paper to five significant figures are not meant to imply that degree of accuracy, but were kept because it was easier than throwing them away. Agreement between two different methods of calculation of hazard rate was within a factor of about 2, and field experience versus calculated results was within a factor of, say, 2–10. These are not unreasonable ratios. It should not be inferred that the author's techniques are the only or the best techniques but rather it should be realized there are many good techniques and their quality is largely determined by the constraints within which one has to operate. This paper should be taken for what it is—a good case history.

R68-13991 ASQC 851; 844

Electra Mfg. Co., Independence, Kans.

ACCELERATION FACTOR DETERMINATION FOR METAL FILM RESISTORS Final Report, 29 Jun. 1963–1 Mar. 1967

G. A. Swartz, W. O. Campbell, and W. E. McLean 1 Mar. 1967 174 p refs

(Contract NAS8-11076)

(NASA-CR-87307; N67-33475)

Studies were conducted to establish acceleration factors for determining the reliability of high stability metal film resistors, to determine modes of failure, and to establish process improvements and stress screening techniques for detecting the presence of the failure modes. Resistor parameters investigated included initial current noise and nonlinear distortion and deviations in resistance and current noise and nonlinear distortion due to applied stress. Metal film resistors from three separate manufacturers representing conformal coated, sealed ceramic sleeves and molded construction were tested. A preliminary sixteen cell matrix of power and temperature was designed to determine the most meaningful stress conditions to be used in extended life testing. Also, in order to determine methods of predicting potential failures, one-half of the resistors in each matrix cell were submitted to various screening techniques. A number of resistors were subjected to various conditions of power stress while the surface temperature was measured by means of the infrared radiation. Author

Review: This must have been a discouraging report to write, since it covers a four-year period and the conclusions are essentially negative: no decent correlations were found nor good relationships established between the desired variables, methods of treatment, etc. But reports of this kind do serve a useful purpose in that they show the uninitiated, the contract monitors, the managers, and others that the road to success is not as smooth as one might gather from reading the success stories published in the open literature. A great many of the near-original data are presented, although in the available copies these reproductions tend to be poor. There have been articles in the open literature highly touting current noise and nonlinear harmonics as an excellent way of predicting life—this report found no such correlation. There is little point in trying to second-guess the authors, since the kind of relationships that one would like to find often do not exist. The report could perhaps have been improved in the following two minor ways. (1) In the analysis of variance, the basic model and the limitations and restrictions could have been given. (2) The acceleration factor is defined as the ratio of reliabilities. This is not the intuitive definition which many engineers think of, nor does it seem to be helpful when the reliabilities are close to one. A much more common and appropriate definition is the ratio of times taken to achieve the same average resistance change. Anyone who is planning a large matrix test on electronic components would do well to study this report carefully. Often we can learn more from other people's unhappiness than we can from their biased success stories. As mentioned above, the negative results also serve to counteract some of the over-optimistic claims in the open literature.

R68-14012 ASQC 853

WHY NOT FRACAS?

Herb Weisbrot (Hycon Mfg. Co., Reliability-Standards Dept. Monrovia, Calif.).

Evaluation Engineering, vol. 7, May/Jun. 1968, p. 12.

An all-encompassing standard form is presented for use in reporting failure, its symptoms, and maintainability time factors; and the need for standardization of failure definitions and reporting is stressed. The form lists various tasks related to design and maintenance; and indicates those tasks for which reliability, maintainability, and quality assurance/control personnel require

information. Standardizing the failure reporting form not only saves time in retraining reliability personnel but also accounts for repair and time-to-repair information. M.W.R.

Review: This short paper is yet another on the subject of new and improved failure reporting forms. It is concerned largely with having the form be of use to the person who receives it, rather than with the details of making it attractive to fill out by the technician who must do that task. The need for standardization cannot be denied, but it is doubtful that many people will find the time and effort to push a universal form, especially when it does not contain their own pet ideas. If such a form contained everyone's pet ideas it would take roughly forever to fill out. Human-factors people have considered this problem elsewhere from the reporting technician's point of view. This paper, as probably intended by the author, should be considered a brief comment on only one aspect of the many problems involved in failure reporting and corrective action.

R68-14016 ASQC 851; 844

ACCELERATED TESTING OF THE MECHANICAL AND THERMAL INTEGRITY OF POLYMERIC MATERIALS.

Jerome J. Lohr, Donald E. Wilson (NASA. Ames Research Center, Moffett Field, Calif.), Frank M. Hamaker, and Willie J. Stewart

In: Proceedings of Structures, Structural Dynamics and Materials Conference, 8th, Palm Springs, Calif., Mar. 29–31, 1967. Conference sponsored by the American Institute of Aeronautics and Astronautics and the American Society of Mechanical Engineers. New York, AIAA, Inc., 1967, p. 453–460. 13 refs.
(A67-23743)

Methods of analysis have been developed which allow the long-time mechanical and thermal stability of polymeric materials to be predicted from experiments conducted over relatively short periods of time. Materials tested included Plexiglas, poly(vinyl chloride), polystyrene, Delrin, and Lexan. The method for accelerated testing of mechanical properties is an application to creep-rupture tests of the time-temperature equivalence concept previously developed for mechanical behavior of polymeric materials. At temperatures from approximately 25 to 125°C below the glass–rubber transition temperature for each polymer, it was found that a 10°C increase in temperature corresponds to approximately a ten-fold decrease in time-to-failure. Thus, experiments which produce a time-to-failure of several days at a given temperature and stress may be used to predict failure times of the order of a year or more for a material temperature 20°C lower. The method for accelerated testing of thermal stability uses the kinetic parameters and extents of reaction determined from thermogravimetric analysis and residual gas analysis. These are used to predict thermal stability of materials over a period of days or weeks from a test requiring approximately 4 hr. Author (IAA)

Review: The use of polymer materials is increasing for aerospace vehicles as it is in most fields, and often the design engineer needs data that are not readily available to him. Some of the properties of polymers which are discussed in this paper are of interest to these design engineers, although one has to be very careful about the definition of failure when the data are used in exact calculations. It would be interesting to see how well the concept of a time/temperature parameter as is common in metallurgy and sometimes in polymers would fit these data, especially if the constant involved were the same for different plastics. Where data are required on actual parts, it is wise to test the finished parts themselves because the properties of many plastics are quite sensitive to molding conditions. Curves obtained from a paper such as this or from the manufacturer of the plastic material should be considered only as rough guides.

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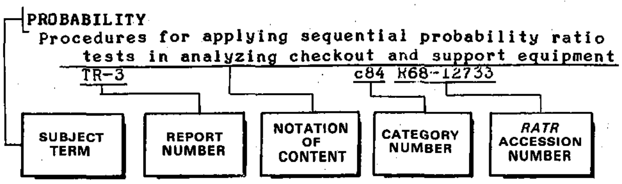

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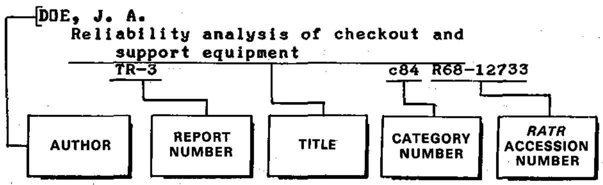

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The Contents of

Reliability Abstracts and Technical Reviews

The first section of *RATR* contains bibliographic citations, abstracts, and reviews. The items (each identified by an *RATR* accession number) are arranged in subject categories based on the first two digits of the codes developed by the American Society for Quality Control. The complete listing of these ASQC codes appears on the inside back cover. Examples of citations of reports, journal articles, and conference papers are shown below. The principal subject field of the item (and therefore the category in which the item appears in the journal) is indicated by the first ASQC code number; related subject fields are indicated by additional code numbers. The appearance of a *TAB, STAR,* or *IAA* accession number indicates that the item has been announced in, respectively, *Technical Abstract Bulletin, Scientific and Technical Aerospace Reports,* or *International Aerospace Abstracts.*

The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

		ASQC CODES
RATR ACCESSION NUMBER	R68-12733 ASQC 844; 413	CORPORATE SOURCE
TITLE	General Equipment Company, Banville, Calif.	
	RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT	PUBLICATION DATE
AUTHOR	John A. Doe 23 Sep. 1966 27 p refs	
CONTRACT OR GRANT	(Contract NAS15-13411)	*TAB* AND *STAR* ACCESSION NUMBERS
REPORT NUMBER	(TR-3; AD-629305; N68-15098) CFSTI: HC \$3.00/MF \$0.65	SALES AGENCY AND PRICE

RATR ACCESSION NUMBER	R68-12739 ASQC 814	ASQC CODE
TITLE	**SEMICONDUCTOR RELIABILITY**	
	Joseph A. Smith (Eastern University, Arlington, Penn.)	AUTHOR AND AFFILIATION
JOURNAL REFERENCE	*Electric Journal,* vol. 8, Apr. 1966, p 478–492.	
	(A68-12569)	*IAA* ACCESSION NUMBER

RATR ACCESSION NUMBER	R68-12765 ASQC 773; 221; 823	ASQC CODES
TITLE	**TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES**	
	Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)	AUTHORS AND AFFILIATIONS
CONFERENCE OR SYMPOSIUM REFERENCE	*Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p*	
	Available from Assoc. of Reliability Eng., New York: \$1.00	AVAILABILITY AND PRICE
IAA ACCESSION NUMBER	(A68-12407)	

VOLUME 8 NUMBER 10

Reliability Abstracts and Technical Reviews

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80 RELIABILITY

R68-14062 ASQC 802

RELIABILITY OF ELECTRONIC COMPONENTS.

C. E. Jowett London, Iliffe Books, Ltd., 1966, 165 p

(A67-20206) $5.88

This book clarifies and presents all the relevant facts concerning the properties and stabilities of various classes of components and materials. The effect of environment and atmosphere on equipment is studied, and possible hazards and best ways of protection are described. The aspects of soldering and crimping of connections are reviewed, and resistors and capacitors are examined. Faults which may occur when using thermionic valves and transistors are detailed, and the principles of operation and applications of metal rectifiers are briefly dealt with. Other subjects discussed include transformers and inductors, relays, rf cables, electrical contacts, printed circuits and wiring, and potted components and encapsulation.

IAA

Review: This is a small, rather high-priced book that deals with the engineering considerations in applying electronic components. It does not give hazard rates for any components, nor does it estimate their useful lives. There will be a minor inconvenience for American readers in that British terminology is used; e.g., by now virtually everyone knows that a valve is a tube and that earth is ground. Some of the abbreviations, for example, p.t.f.e. are never defined but the astute reader will undoubtedly surmise that it means polytetrafluoroethylene (TEFLON). This book is apparently not intended for a single class of readers. Considerable space, for example, is devoted to explanation of power factor, etc. of capacitors and yet many other terms are introduced as if the reader were familiar with them. Much of the text is devoted to explaining the function of some of the components, particularly capacitors, which is more appropriate, of course, in a book on basic ac circuits than in one on the reliability of electronic components. On the whole the book can be useful to someone searching for some practical knowledge about these parts, who otherwise would have very little of it. But he has to be careful about taking the details seriously since (a) if he is a novice the many editorial errors may bother him and (b) the book contains numerous deficiencies. Some illustrations of these deficiencies are the following. (1) The section and subsection headings are not clearly enough identified and often it is not clear what is subordinate to what. (2) Some of the practical information is too specific, probably specific to a particular company or specification, but that specificity is not identified. Examples of this are listing the number of case sizes a capacitor might come in or the number of turns a five μH inductor would have. (3) Descriptions of many phenomena are hidden under special types of components and this is especially true in capacitors. Instead of first discussing the various properties of capacitors in general (such as leakage current, dissipation factor, remnant charge) they seem to be put wherever the author has some information about them on the particular type of capacitor. (4) It must be kept in mind that virtually always the author is giving *a* solution to the indicated problem, not *the* solution, but he does not so state. It would be easy for the novice to get the impression that *the* answer is being given. Examples of miscellaneous comments which could have been stated more accurately are given below. (1) "Water is a good conductor..." Pure water is, of course, an excellent insulator; it is contaminated water that is a good conductor. (2) The author states that oxide film resistors are undoubtedly the best type for long-term stability, etc. This obviously is a point of view which varies depending on one's immediate past experience, what happens to be available, and for whom one works. (3) "Where long life is important the resistor should be derated to 1/2 of its rating..." This obviously is only one point on the "stress"-life curve for the component. The derating also depends on what factor of safety the manufacturer has included. (4) There are several typographical errors in units where m, for example, is used for M, a factor of 10^9 difference. (5) One of the large manufacturers of carbon composition resistors would probably take issue with some of the descriptions of them. (6) "The lower limit of capacitors is $-40°$C..." Obviously this depends on the type of capacitor. (7) There is not enough discussion of the problem of series inductance in capacitors. To say that all capacitors have leakage resistances on the order of thousands of megohms is somewhat too sweeping. Many electrolytics will have leakage resistances appreciably less than that. In the discussion on ac current losses in capacitors, the calculations for this as a function of frequency are not at all clear and are probably incorrect. (8) Discussing transistors and diodes: "It is therefore apparent that manufacturers' reliability figures will always be worse than those in the field..." Would that were so! (9) "... Since the ac increment and copper loss varies as the sixth power of the wire diameter..." The source of that "fact" is not given and it is contrary to common expectation. (10) "The inductance must be accurate to $\pm$ 0.5% since the number of turns for an inductance of 3.5 μH is 33, the removal of one turn will change the inductance by 6%." This is supposed to be a general comment regarding inductors but is obviously extremely specific to a particular application and a particular manifestation of a particular inductor. (11) For high-speed relays the author says that the relay contacts are platinum. Obviously this is not always so. Under relays no mention is made of the problem of arcing to the case of small enclosed relays. As can be seen from the above comments, the book would have profited a great deal from more careful proof reading and editorial management. The coverage is spotty; for example, tantalum electrolytic wet capacitors received 8.5 pages, general aluminum electrolytic capacitors none, high frequency aluminum electrolytic capacitors, 2 pages, transistors received 5 pages.

Some of the comments are very good. The difficulty is that the novice is not able to separate them from the misleading statements. All in all it is difficult to recommend this book without the author's first having corrected some of the gross deficiencies.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-14037 ASQC 810; 833
NON-STANDARD PART SELECTION AND WAIVER APPROVAL REQUIREMENTS.
Andrew G. Stavros (Kollsman Instrument Corp., Engineering Standards, Syosset, N. Y.).
In: Transactions of 1967 Spring Product Assurance Conference and Technical Exhibit, Long Island, N. Y., Apr. 15, 1967. Conference sponsored by the American Society for Quality Control, the Standards Engineers Society, and the Society of American Value Engineers. Arno Press, Inc., [1967], p. 165–176.

Non-standard parts are considered in terms of their use and relationship to military standard parts; and complications which arise from the use of non-standard parts are examined. A parts list and data sheet are shown for non-standard parts; and means by which government approval can be obtained for non-standard parts is discussed. Some of the usual reasons for disapproval are reviewed. M.W.R.

Review: This competent description of approval procedures for the use of non-standard parts on military contracts would make good handout material for new engineers and administrators such as purchasing agents. Component engineers should be aware of the contents of this paper. The author sounds somewhat like a spokesman for the Government. The contents of this paper apply to certain DoD contracts; nothing is said about part-approval requirements where NASA is the Government customer.

R68-14038 ASQC 813
RELIABILITY DEVELOPMENT ON THE GE4.
D. Q. Marshall and H. T. Gieryn (General Electric Co., New York, N. Y.).
Society of Automotive Engineers, National Aeronautic Meeting, New York, Apr. 24–27, 1967. 31 p.
(Paper 670317; A67-32979) Members, $0.75; nonmembers, $1.00

Identification of six reliability methods used to insure early reliability of the SST engine. One of these techniques, the Reliability Analysis Program, is fully described, and early results of all of the programs in SST development are given. It is emphasized that required improvements are indicated before testing, thus providing a basis for using the program as a means of improving on specific areas of design rather than as an exploratory tool alone. IAA

Review: For those readers who are unfamiliar with the designation GE4, it is the turbojet engine for the forthcoming supersonic transport. The reliability program described in this paper is evidence of the fact that the commercial carrier portion of the aviation industry has long been adept at using and contributing to the development of high-reliability design approaches. It is always pleasing to hear of a sensible reliability program being implemented on non-military efforts because local management believes in it rather than because the customer is demanding it. The many figures give detailed illustrations of the actual implementation of the tasks of this reliability program, making the paper of value to those concerned with similar programs.

R68-14058 ASQC 810
AVOIDING PRODUCT SAFETY BOOBY-TRAPS.
George A. Peters (Product Safety Research Corp., Sherman Oaks, Calif.).
Production, vol. 61, May 1968, 4 p.

Product safety and hazards are considered in terms of manufacturing philosophy and operations, and the responsibility of manufacturers as determined by the courts is discussed. Problem-causing areas during design, manufacturing, purchasing, and servicing products are treated; and the need for a many-faceted program is stressed for insuring safety at the manufacturing level. Brief mention is made of some cases and their large court settlements; and possible safeguards to manufacturers are enumerated. The role of insurance and the present-day social climate are also mentioned. M.W.R.

Review: The discipline of product safety is coming to the forefront and the already-overburdened designer may well feel it's about time people got together with themselves about what is important. Like reliability, safety considers a subset of the various failure events and thus bears a close kinship to it. One of the places where "theoretical" reliability parts company from practical reliability and from product safety is that often "theoretical" reliability concerns itself only with what happens when the equipment is used in the intended way; whereas practical reliability and product safety are concerned with what happens when the equipment is used in a way the operator feels is appropriate. It is perhaps natural that many people would want to combine the discipline of safety and that of reliability in the same group since they have so much in common. Of course, much depends on not only the organization chart of the company, but on the way the company is actually run and the reasons why people are behaving the way they do. One would like to think that the designer is actually responsible for the various product characteristics and the tradeoffs that must be made or, at least, for clearly presenting his management with the tradeoffs that can be made; and that groups such as reliability, safety, value engineering are consultants/specialists who advise the designer and the manufacturing department in areas where the special expertise is needed. But in the real world things do not always work out this way—heads of some departments are weak and others are strong and in order that certain desirable things get done, someone has to do them. Thus often one may find that a reliability engineer is trying to do the design engineer's job or that quality control is trying to do the shop's job. But regardless of how it gets done, it is important that the discipline of product safety be incorporated not only in consumer products but in those for the aerospace and defense industries as well.

R68-14061 ASQC 810
ORGANIZE AGAINST PRODUCT FAILURE.
Richard R. Landers (TRW Systems Group, Reliability Dept., Redondo Beach, Calif.).
Machine Design, vol. 40, June 6, 1968, p. 136–143.

A hypothetical exchange of memos and letters among a customer, manufacturer, and failure review people is used to show how complaints can assist industry in correcting product failures. A failure review board procedure is included that delineates tasks, participants and their responsibilities, and documentation of failure reports. In the hypothetical case presented, both the agenda for the review board meeting and the actions taken as a result of the meeting are presented. M.W.R.

Review: There is a tendency in many companies to reorganize when something goes wrong; but an organization chart does not, per se, cause things to be done differently. If the reorganization

in fact makes it easier to do the helpful things, more difficult to do the unhelpful, and harder not to do helpful things, an improvement will have been made. This informally written, easily read article shows how in some companies it is difficult to find out who has authority and responsibility for corrective action or for deciding whether or not such action should even take place. It also points out how a minor change in organization can sometimes effect an improvement in the procedures, and that different companies may wish to adopt different organizations and procedures. But the important thing for the reader to remember is that the reorganization does not do the job—it is still people who do the job.

R68-14068 ASQC 815; 844

THE IMPACT OF THE FLIGHT SPECIFICATIONS ON SEMICONDUCTOR FAILURE RATES.

Jayne Partridge and L. David Hanley (Massachusetts Institute of Technology, Dept. of Aeronautics and Astronautics, Instrumentation Laboratory, Cambridge, Mass.).

In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 20–30. 5 refs.

(A68-27240)

The procurement, screen and burn-in, and field history of the semiconductor parts in the Apollo Guidance Computer are given. Both field failures and variability of performance through screen and burn-in are directly related to changes occurring in the parts manufacturer's facilities. The problems of developing and sustaining high reliability are discussed. Author (IAA)

Review: Since many of the original Apollo documents are not available to the general public, it is helpful when reports are made at open meetings like this one. This particular group, working on the Apollo guidance computer, has followed a policy of (a) minimum or no redundancy and (b) intensive screening of parts in order to achieve the requisite reliability. This paper is a good summary of the progress, the trials, and the tribulations which are the result of such a policy. There is not unanimous agreement that this procedure is the way to go. For example, many people prefer redundancy while some prefer buying integrated circuits that have the greatest possible commercial/military production and then performing screening tests on those. Some of these differences in policy arise from different requirements, others from different trade-offs, and others because people just have different likes and dislikes. Regardless of any of those conditions, however, this is a valuable paper for both design and reliability engineers who are in the electronics business.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-14022 ASQC 824

PRINCIPLE OF MAXIMUM ENTROPY AND ITS APPLICATION IN RELIABILITY ESTIMATION OF AIRCRAFT STRUCTURES.

Haresh C. Shah (Pennsylvania University, Towne School of Civil and Mechanical Engineering, Philadelphia, Pa.).

In: Structures, Structural Dynamics and Materials Conference, 8th. Palm Springs, Calif., Mar. 29–31, 1967, Proceedings. Conference sponsored by the American Institute of Aeronautics and Astronautics and the American Society of Mechanical Engineers. New York, AIAA, Inc., 1967, p 321–338. 6 refs.

(Contract N-156-45588)

(A67-23730)

The principle of maximum entropy is used to estimate the prior probability distribution of the life to failure of horizontal tail surfaces. The tests were conducted at the Aeronautical Structures Laboratory of the Philadelphia Navy Base. The specimens were tested under constant and variable amplitude tests. In estimating the probability distribution of life to failure, mean and variance functions are assumed to be known. The effect of cutting off the load frequency curve at the high and low load ends is investigated. It is found that there is no considerable effect in fatigue life by cutting off the low load levels. This can be concluded by looking at the effective loading blocks in spectrum one, two and three. The elimination of highest load level as in spectrum four has some effect on the fatigue life. For variable amplitude test results, Cortan–Dolan hypothesis is used. Results are presented in form of tables and charts. Author (IAA)

Review: This paper tries to do too much at one time, expends too much of the paper on trivia, and does not treat the important aspects of the problem adequately. There are several levels of the theory at which the paper can be reviewed; this review will begin at the level furthest away from the basic assumptions. The principle of maximum entropy did not need to be introduced at all. A basic assumption in the original investigation and data analysis was that the results were logNormally distributed. Implicit in the analysis of this original data was the existence of the interval over which the logNormal distribution would be normalized. Since it is very likely that conventional formulas were used, the normalization interval was from 0 to $+\infty$ for number of cycles—which corresponds to $-\infty$ to $+\infty$ for log-cycles. There is nothing wrong with using this normalization interval, it is the most convenient one that can be chosen, and it introduces negligible error over the actual limit. There is some difficulty in trying to decide what is the lowest number of cycles in which fatigue failure can occur. (There are those who would argue, for example, that one cycle is the smallest in which fatigue can occur; some say one-quarter cycle, i.e., the first maximum. The more adept applied mathematicians would point out that the argument is fruitless since the difference in the equations is negligible and one might as well assume the full interval.) If this had been done the author could have gone through the conventional Corten–Dolan analysis and have written a reasonably standard paper. There would then be nothing to distinguish this paper from any other such treatment. Going back one step further toward the basic assumptions, consider the equations which were developed by Tribus and referenced by the author. For some reason the author chose to copy Tribus' normalization interval without a critical analysis as to what its effect on the present paper would be. The author also nimbly alternates between cycles and log-cycles for his variable without any regard to the implications in the theory. Much of the long tedious arithmetic in the paper is devoted to evaluating the normalizing constants according to the Tribus formulas. If the normalization interval more appropriate to this problem had been used, that arithmetic would have been much simpler and the paper would have appeared less difficult. (Most of the algebra in the text that may disconcert the reader is not directed toward the fundamental problem of representing the data in terms of the theory, but is merely devoted to calculating and having to handle the complicated normalization procedure.) It would have been much less disturbing had all of this material been either eliminated or relegated to an appendix.) The Δn and ΔN_1 are not defined, yet

appear in the formulas. On page 322 there are comments and inferences about distributions wherein the standard deviation equals the mean. The author states that this situation implies the exponential distribution. On the contrary, since an indefinitely large number of distributions can have this property it needs to be explicitly proved, under these particular circumstances, that the conclusion does follow from the premise. The fact that the author finds support for this statement in the Tribus text does not make it any more correct. Finally, on the next most basic level, the adaptation of the mathematical derivation to the physical situation is fraught with some problems—unless one's intuition is the same as the author's or that associated with the Tribus reference. Granted that one wishes to use the principle of maximum entropy, the problems are merely beginning. The Tribus text then goes on to maximize the entropy under the presence of several constraints. The first and most general of these is that the sum of the probabilities must be 1 (implicit in this, and fortunately it comes out to be so, is the fact that the probabilities must all be positive). The remaining constraints in the Tribus text are of the form that the mean value of some function of the variable is fixed with respect to modifying the probability distribution. The functions appear to be quite arbitrary (undoubtedly subject to being reasonably well-behaved). The expression for maximizing the entropy (assuming an extremely large number of events) is, in the absence of any constraints, accomplished by making the p_i of each event very large. The first restriction ($\Sigma p_i = 1$) limits the p_i's to a hyperplane. Each succeeding constraint limits to one less dimension the sets of p_i to be considered. The constraints are linear in the p_i's. But it is not at all clear in the physical situation (and concern oneself at the moment with the fatigue of metals) just why one picks mean value constraints. Next, granted that mean value constraints are to be used, how many of them should one pick? Then, what should those functions themselves be? The author has difficulty deciding whether the function of time should be N or log N. These points are not well explained in the Tribus text and the author of this article makes no attempt to do anything but blindly copy the Tribus material. In short, this paper contains many deficiencies on several levels and should not be construed as an example which follows demonstratively and inexorably from Jaynes' hypothesis of maximum entropy (minimum prejudice). Other articles in the literature which purport to apply the same Jaynes' principle have similar deficiencies.

R68-14023 ASQC 823

Hughes Aircraft Co., Culver City, Calif.

PROJECT "DIODE RELIABILITY PREDICTION TECHNIQUE"

C. M. Ryerson Washington, NASA, Feb. 1967 87 p refs

(Contract NAS5-9638)

(NASA-CR-702; N67-16670) CFSTI: HC$3.00/MF$0.65

This project has succeeded in its objective of developing a new approach to reliability prediction for semiconductor diodes based on realistic mathematical models. A new rationale for reliability modeling was developed by defining reasonable approximations and expressing in useable mathematical form the natural processes of degradation to failure under stress. A law of failure rate prediction was thus established for diodes. Some of the uses of this law can be summarized as follows: (1) to determine if a lot of parts is typical of the standard part; (2) to establish a new model for similar but different types; (3) to evaluate the differences between supposedly identical lots; (4) to compare products from different suppliers; (5) to evaluate consistency of quality control in a supplier's plant from lot to lot; (6) to compare the effectiveness of quality control between suppliers for the same type parts; (7) to establish new constants and models for different part types; and (8) to purify and perfect the model to deeper levels of interaction simulation. Author

Review: This is the report from which the author's paper "Mathematical modeling for predicting failure rates of component parts," in Proceedings Sixth Annual Reliability Physics Symposium, Nov 67, p. 10–15 was summarized. The comments given in the review of that paper which appears in this issue of RATR are appropriate to this report. That is, the discussion of the philosophy of models is good, but the actual model contains a great many arbitrary constants and some arbitrary functions, which is a distinct disadvantage in terms of being definitive; and the optimism about the magnitude of the scientific breakthrough involved is not justified. The section on experimental design is as reasonable as can be developed without the knowledge of how the experiments are actually going to turn out. Those results, of course, could force a distinct change in the experimental plans and even in the models themselves.

R68-14043 ASQC 825; 614; 838

INTEGER PROGRAMMING FORMULATION OF CONSTRAINED RELIABILITY PROBLEMS.

F. A. Tillman (Kansas State University of Agriculture and Applied Science, Manhattan, Kan.) and J. M. Liittschwager.

Management Science, vol. 13, July 1967, p. 887–899. 22 refs.

(Grants NSF GK-818; NGR-17-001-005)

(A68-24769)

Investigation of the solution by integer programing of reliability optimization problems which are subject to linear and nonlinear separable restraints. In particular, the following problems are solved: (1) maximizing reliability for a parallel redundancy system subject to multiple linear restraints, (2) minimizing cost of a parallel redundancy system subject to multiple nonlinear and separable restraint functions while maintaining an acceptable level of reliability, and (3) optimal choice of design for a parallel redundancy system. Also discussed are the necessary alterations to the above formulations for problems involving standby redundant units. Author (IAA)

Review: The approach taken in this paper, i.e., linear programming where the decision variables are either zero or one, allows the handling of general reliability allocation problems such as alternate design approaches, active and standby redundancy, and situations involving multiple non-linear constraints. Separability in the reliability function and in the constraint functions is the key. Those interested in reliability allocation will want to be aware of this approach. The general features which can be treated are those for realistic problems. The authors note that none of their references, involving dynamic programming, treat the problem in the generality made possible by the integer programming approach. The separability feature which allows the linear programming integer approach will also allow a dynamic programming approach, as noted in the paper covered by R67-13406. The difficulty with dynamic programming is that a problem with more than one restriction is difficult to solve. The value of the integer programming approach is that it allows one to solve a problem involving multiple restrictions. Computation time would be a key consideration and no comments are given in the paper on what might be expected. In any case, it would be extremely desirable to have alternate ways of treating the same problem, as one can serve as a check on the others.

R68-14044 ASQC 825; 614; 833

OPTIMUM REDUNDANCY FOR MAXIMUM SYSTEM RELIABILITY BY THE METHOD OF CONVEX AND INTEGER PROGRAMMING.

Koichi Mizukami (Toronto University, Toronto, Canada).
Operations Research, vol. 6, Mar./Apr. 1968, p. 392–406. 17 refs. Research supported by the National Research Council of Canada and the Sakkokai Foundation of Japan.
(A68-29054)

Demonstration of the applicability of convex and integer programming to the problem of determining optimum redundancy. A design method to maximize system reliability subject to several constraints on total cost, weight, and volume is described, and numerical examples are given to illustrate the procedure for the case of parallel redundancy. IAA

Review: Yet another method is proposed in this paper for the reliability redundancy allocation problem. (See also "Integer programming formulation of constrained reliability problems," by Tillman and Liittschwager, *Management Science,* Jul 67 and "Linear programming and reliability of multicomponent systems," by Kolesar, *Naval Research Logistics Quarterly,* Sep 67, which are reviewed in this issue of RATR.) The problem is formulated for using convex programming. Here the objective function is approximated by piecewise linear approximations and conventional linear programming is then used. Thus the constraints will still be linear, but multiple constraints are readily treated. The number of alternate approaches being proposed for redundancy allocation problems continues to increase, each with its particular advantages and disadvantages. This situation is, of course, a very desirable one as it provides a means of checking a solution. This paper appears to be the first to suggest the convex programming approach for redundancy allocation.

R68-14050 ASQC 821; 882
A METHOD FOR PREDICTING SYSTEM DOWNTIME.
Eginhard J. Muth (General Electric Co., Daytona Beach, Fla.).
In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 18–25. 11 refs.
(A68-11668)

Study of the probabilistic behavior of repairable systems with respect to the properties and the prediction of downtime. Only two system states, the operating and the failed state, are distinguished. The system is defined by a reliability network and by the failure rate and repair rate of each component. The time-to-failure and the time-to-repair of the components are assumed to be exponentially distributed. A criterion of system worth is the random variable downtime D(t), and is defined as the time the system is down during the time interval (0,t). It is shown that the beta distribution is a suitable approximation for the conditional distribution of D(t)/t, assuming that at least one failure has occurred and that for t greater than 20 mean failure times the distribution of D(t) is practically normal. IAA

Review: This is a good theoretical paper which derives an expression for down-time and makes the usual simplifying assumptions that repair and failure times are exponentially distributed, statistically independent, etc. The approximate probability distribution for this function is derived. It is, of course, related to the Availability (as shown by the author). The downtime of a system is one of the useful figures-of-merit for it. The designer will, of course, also be considering other figures-of-merit. This paper is more for other theorists and for design engineers who have considerable analytic facilities available to them. While not checked in its entirety, the mathematics appears quite competent.

R68-14052 ASQC 821
A BASIC INTRODUCTION TO RELIABILITY ENGINEERING.
Harold C. Jones (Westinghouse Defense and Space Center, Aerospace Div., Baltimore, Md.).
In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 34–39. 1 ref.

Reliability prediction, reliability control during design, and reliability verification are discussed in general terms; and some mathematical treatment is offered for determining mean time between failure by an exponential model. The infancy of reliability engineering as a discipline is stressed, and its importance in present-day military technology and industry is noted. M.W.R.

Review: This paper can be given a better review as a talk than as an archival document, because as a document the details can be studied and picked apart by anyone who so desires. Many of the details will not stand up too well under this procedure. Therefore this paper should be read for the qualitative information in it rather than regarding any of the specifics as gospel. For example, it is easy to infer that somehow the exponential assumption and the series model are related, and that the series model requires the use of the "product rule" of probability. None of these are actually true. One can use the series model regardless of the exponential assumption and the "product rule" holds only for statistically independent events. In his Figure 2 for the overlap of stress and strength, the area of overlap is cross hatched which leads some people to think that it is the area under the two curves which has significance whereas, of course, only the length and location of the abscissa between the points where the two curves are zero has importance. There are similar difficulties with the brief statistical treatment in the testing section. But the qualitative aspects of the paper are good, e.g., the description of what reliability engineering is all about, especially during design and verification. It is very likely that those who heard the talk (and thus did not have time to assimilate the technicalities that could mislead them in the written paper) were able to profit from it.

R68-14057 ASQC 824
Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
A THEORY FOR RAPID DETERMINATION OF RELIABILITY INDICES FOR MACHINE AND INSTRUMENT PARTS [TEORIYA USKORENNOGO OPREDELENIYA POKAZATELEY NADEZHNOSTI DETALEY MASHIN I PRIBOROV]
V. N. Treyer 28 Feb. 1967 7 p refs Transl. into ENGLISH from Akad. Navk Belorussk. SSR (USSR), v. 9, no. 8, 1965 p 541–543
(FTD-HT-67-30; AD-659667; N68-10603)

Ordinary methods of testing machine and instrument parts for reliability are too time-consuming. A theory is developed for accelerating reliability tests which will give valid results. The theory is based on a distribution law and a hyperbolic law of service life. Samples are tested by step-wise loading until 50% of the objects fail. Meanwhile two other sample lots are tested under constant load. Results are manipulated mathematically to give reliability and service life indexes that can be extended to parts that have not been used. Author (TAB)

Review: This unedited rough draft translation is somewhat difficult to decipher, but the essentials of the argument are as follows. 1. The life follows a power law, i.e., $t \times s^k$=constant, where t is the life and s represents "stress." This particular form has severe disadvantages since t is a random variable; these disadvantages are not considered in the report. 2. The linear theory of cumulative damage is used; the damage rate is considered to be s^k. 3. A step-stress test, until half of the parts have failed, is run first. An equivalent load which would have caused failure in the same

length of time under constant "stress" is calculated using the linear cumulative damage theory. 4. Apparently the purpose of running the previous test is merely to find the equivalent load, and this is the maximum load at which constant "stress" tests are run. 5. A somewhat lesser load is also used to run constant "stress" tests. 6. The Weibull distribution is apparently assumed for times to failure and in the practical case the shape parameter (exponent on t) is taken to be independent of load. Further, the time under consideration in all of these cases is the time to failure of a certain quantile of the sample (this may be a population parameter estimated from the data or it may be the actual sample time). 7. The scale parameter of the Weibull distribution is assumed to be a function of "stress" and must be found from the sample. In general, this paper confuses issues by not considering the parameters of the distribution to be functions of stress but discussing the time (a random variable) instead. This complicates the situation no end and probably renders the results of negligible value. This type of problem is well covered in the American literature; therefore, no one need consult this paper.

R68-14065 ASQC 825; 614; 838

Columbia Univ., New York.

LINEAR PROGRAMMING AND THE RELIABILITY OF MULTICOMPONENT SYSTEMS.

Peter J. Kolesar Washington, Office of Naval Res., Sep. 1967, 12 p refs Repr. from Naval Res. Logistics Quarterly, v. 14, no. 3, Sep. 1967 p 317–327
(Contract NOnr-266(55))
(NAVSO-P-1278; AD-659652; N68-31997)

Several problems in the assignment of parallel redundant components to systems composed of elements subject to failure are considered. In each case the problem is to make an assignment which maximizes the system reliability subject to system constraints. Three distinct problems are treated. The first is the classical problem of maximizing system reliability under total cost or weight constraints when components are subject to a single type of failure. The second problem deals with components which are subject to two types of failure and minimizes the probability of one mode of system failure subject to a constraint on the probability of the other mode of system failure. The third problem deals with components which may either fail to operate or may operate prematurely. System reliability is maximized subject to a constraint on system safety. In each case the problem is formulated as an integer linear program. This has an advantage over alternative dynamic programming formulations in that standard algorithms may be employed to obtain numerical results. TAB

Review: In his introduction, the author gives a brief but comprehensive summary of the application of optimization methods to reliability problems. These few paragraphs can provide an understanding of the state-of-the-art of reliability optimization. For those who need more detail, the references will be useful. The application of zero-one integer linear programming to several particular problems is described. These are ordinary active redundancy, two failure modes per item, and premature operation. Principal advantages (over dynamic programming approaches) are that multiple constraints are treated and that general linear programming computer routines are available. The discussion concentrates on the structuring of pertinent mathematical models and no numerical examples are given; however, the paper can be followed readily by the practical person interested in real-world applications as well as by the theorist. This is a permanent reference item for those interested in the application of optimization techniques to reliability allocation problems. Those interested in this topic area should see also R66-12815 and R67-13330, as well as the following two papers which are reviewed in this issue of RATR: "Integer programming formulation of constrained reliability problems," by Tillman and Liittschwager, *Management Science*, Jul 67, and "Optimum redundancy for maximum system reliability by the method of convex and integer programming," by Mizukami, *Operations Research*, Mar–Apr 68.

R68-14067 ASQC 823

MATHEMATICAL MODELING FOR PREDICTING FAILURE RATES OF COMPONENT PARTS.

Clifford M. Ryerson (Hughes Aircraft Co., Culver City, Calif.).
In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 10–15.
(A68-27238)

Description of a new intermediate level of reliability modeling, related to predicting failure rates of component parts. Models at this level relate probable failure rates of devices to their strength and performance properties from a consideration of the electrical and physical stresses of circuit application and local part environment. An example of an intermediate-level mathematical model for semiconductor diodes is given. It illustrates how failure mechanism, part strengths, and application stresses interact and affect the failure rate of component parts. When this modeling approach has been applied to all part types and various constants and parameters are derived from empirical tests, accurate failure rates for any specific application may be predicted. IAA

Review: This paper is typical of others written by the author and contains much good philosophy about the art of creating models. The final form of the basic model contains inordinate numbers of arbitrary constants and arbitrary functions. There are many more than can be fitted reasonably well to the data under the present state-of-the-art and for some time into the future. The exponential form of the model should not mislead one into thinking that the model must remain so, since an arbitrary function as an exponent can readily convert that factor into, say, a polynomial. The conclusions are extremely optimistic about the present and near-future of modeling. It is likely to be a long time before the hopes expressed therein are realized. This is a summary of the author's report "Project 'Diode Reliability Prediction Technique'," NASA CR-702, Feb. 67, with the exception that the material on proposed design of experiments has been wisely omitted.

R68-14072 ASQC 824

CAUSAL BASIS FOR SYSTEM FAILURE RATE CALCULATIONS.

R. G. Stewart (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Research Labs., Palo Alto, Calif.).
In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 166–169.
(A68-27246)

Study of system failures due to degradation at constant stress. It is proven that the intrinsic system characteristics are as important as the device characteristics in determining the system failure rate. In particular, for a simple N-stage linear amplifier without feedback, it is shown that the failure rate of a stage can for some failure modes be increased greatly by virtue of the gain in the succeeding stages. This proves that calculating the system failure rate as the simple sum of device failure rates in general is incorrect and may significantly underestimate the true failure rate. A "failure rate level diagram" is introduced as a tool for calculating the failure rate of circuits and systems. IAA

Review: How this paper fitted into the category of flash papers/recent results is hard to tell, since the differences between drift and catastrophic failure have been known for many years. This is a well-known problem (concerned with merely adding hazard rates) and where engineers have the data to do better, they usually do it. With regard to the author's example, a knowledgeable design engineer, for at least twenty years, has generally assumed that only the drift of the first stage is important (that the succeeding amplification makes the drift in the latter stages negligible) and proceeds to calculate the point where the output has drifted too far by looking at the drift of the first stage and the succeeding gain. When engineers do not have such nicely-defined things to work with, they may wind up adding hazard rates to get a ball-park estimate. The term "ball-park" is deservedly applied and is used in such definitive publications as the RADC Reliability Notebook (for this very reason among others). For those design and reliability engineers who were not aware of the distinction between drift and catastrophic failure, the author has performed a useful although tortuous service. For those who were already aware of the fact, the paper will have no value.

83 DESIGN

R68-14025 ASQC 830; 824
RELIABILITY OF MICROWAVE RADIO RELAY SYSTEMS.
L. G. Abraham (Bell Telephone Labs., Inc., Holmdel, N.J.).
IEEE Transactions of Communication Technology, no. 6, Dec. 1966, p. 805–823.

Outages of microwave relay systems due to propagation fading can be computed from fading data on individual channels by a model of selective fading that assumes fading in different channels may be both time and frequency correlated. Heuristic arguments are used for the model, which can account for the effect of design changes, including the fading margins, the number of working and protection channels, the width and allocation of radio channels, the number of radio hops per switching section, and equipment failure rates. The model is extended to 4000-mile yearly outage, variations in noise distribution are considered, and some results are included on fading distribution for a heavy-fading switching section consisting of eight hops of approximately constant lengths of about 30 miles. An appendix details the computation of the factors that convert fading probabilities per channel to outages per working channel and for other factors relating fading probability in a radio relay system. M.W.R.

Review: In the early 1950's the Bell System's microwave radio relay grid criss-crossed our continent and made coast-to-coast network television programming a reality. The greatest unknown factor in the original design of the system was its reliability (See A. D. Hall, *A Methodology for Systems Engineering*, Van Nostrand, 1962). Quite apart from equipment reliability was the erratic behavior of the radio medium at the frequencies which had to be used. Very little was known about this fading at the time and that which was known did not encourage complacency. Mr. Abraham's paper represents an attempt to construct an empirical model, based partly on logic and partly on observed data, to explain failures in microwave radio relay systems due to both equipment failure and fading. An adequate model of these phenomena is needed in order to design better radio relay systems for future application. The subject of the paper is more specific than general. Its specific subject matter is of wide-spread importance in the telecommunications industry, however, and it affects all of us to some degree—most of the time that the sign appears on a TV screen saying "Sorry, Telephone Company Equipment Problems," it is due to trouble on the radio relay system with which Mr. Abraham is concerned here. The paper was one of Mr. Abraham's last—he died shortly after it was written.

R68-14033 ASQC 836
COMPETITIVE PRODUCT DESIGNS VIA DESIGN REVIEWS.
Richard M. Jacobs (Westinghouse Electric Corp., Headquarters Engineering, Pittsburgh, Pa.).
In: Transactions of 1967 Spring Product Assurance Conference and Technical Exhibit, Long Island, N. Y., Apr. 15, 1967. Conference sponsored by the American Society for Quality Control, the Standards Engineers Society, and the Society of American Value Engineers. Arno Press, Inc., [1967] p. 111–119. 4 refs.

Case histories are presented to show how design reviews have been used to improve product performance and reliability. Although some of the design reviews have increased product cost, overall estimates indicate savings along with better products. Design review is defined as a formal, documented, and systematic study of product design by specialists not directly associated with its development. The general procedure used in the review is outlined; with design reviews scheduled during the conceptual, development, and production stages. M.W.R.

Review: This paper is the same as the one covered by R66-12528.

R68-14039 ASQC 831; 833; 838; 873
SYSTEM ENGINEERING FOR RELIABILITY AND EASE OF MAINTENANCE.
K. F. Rankin (Plessey Co., Ltd., Systems Development Div., Poole, Dorset, England).
(Institution of Electronic and Radio Engineers, Institution of Production Engineers, and Institution of Electrical Engineers, Joint Conference on the Integration of Design and Production in the Electronics Industry, Nottingham, England, July 10–13, 1967, Proceedings.) Radio and Electronic Engineer, vol. 35, Feb. 1968, p. 67–80. 10 refs.
(A68-21545)

Discussion of the lessons learned from several years of investigation into the performance of a large air traffic control (ATC) data processing system. To achieve the requirements of reliability and ease of maintenance, the time between faults must be made as long as possible, while the time required to clear a fault must be reduced to the minimum. The practice of building up some degree of system redundancy with standby equipment is also one that can be employed to ensure that the occurrence of a fault does not cause an appreciable loss of system facilities. The experimental ATC system, on which the original findings were based, illustrates the feasibility of designing a high standard of reliability into data-processing equipment. Extensive data on the performance of the system have since been analyzed and used to improve further the reliability factor. Author (IAA)

Review: This report is the same as the paper covered by R68-13877.

R68-14041 ASQC 837
A STATISTICAL DESIGN PROCEDURE FOR RELIABLE CIRCUIT MODULE.
Ayatomo Kanno (Hitachi Ltd., Totsuka Plant, Yokohama, Japan).
Electronics and Communications in Japan, no. 1, 1967 p. 72–80. 5 refs.

An expanded overstress Monte Carlo method has been proposed for the design of circuit modules. Probability distributions were based on drift failure of the elements of the circuit modules,

and a computerized simulation of accelerated endurance testing followed. Interval estimates were thus obtained for failure rates corresponding to a specified point in time by computations of short duration. Reliability approach to the design of circuit modules is discussed; and, although the NOR circuit is considered, the results are applicable to a wide variety of circuit modules and conditions. The design procedure is detailed, and design conditions are tabulated. Flow diagrams are included, and the basic equation is constructed. The distribution of characteristic values of each element is tabulated, and an example of computer output is included. An overall comparison was made between the expanded overstress Monte Carlo design method and the worst case design method. M.W.R.

Review: The use of the Monte Carlo technique for circuit drift analysis is a well-treated subject in the reliability literature. Of main interest in this paper are the detailed remarks concerning the distributions which were used, the analysis flow diagram, and the computerized computation. The readability of this paper is poor in places, apparently because of problems with the translation, but usually the reader will be able to follow the ideas.

R68-14042 ASQC 831; 612; 821; 838

ON-LINE RELIABILITY CALCULATIONS TO ACHIEVE A BALANCED DESIGN OF AN AUTOMATICALLY REPAIRED COMPUTER.

W. G. Bouricius, W. C. Carter, J. Paul Roth, and P. R. Schneider (International Business Machines Corp., Thomas J. Watson Research Center, Yorktown Heights, N. Y.).

In: NAECON'67; Proceedings of the Annual National Aerospace Electronics Conference 19th, Dayton, Ohio, May 15–17, 1967, Technical Papers. Conference sponsored by the Dayton Section and the Aerospace and Electronic Systems Group of the Institute of Electrical and Electronics Engineers. Dayton, Ohio, IEEE, Inc., 1967, p. 243–246. 7 refs. Research sponsored by the International Business Machines Corp. and USAF.

(A67-32501)

Description of a method for iterative, on-line reliability calculations arising from architectural investigations of an automatically repaired space computer. A reliability model is constructed for a class of computer organizations which includes various forms of multiplexing to achieve high reliability; the model is programed on an interactive time-sharing computer system. The program is used to proceed from an initial computer configuration to a design in which the reliabilities of the various parts are "balanced" or adjusted so that each contributes close to its predetermined fraction of the probability of failure of the total design. IAA

Review: A reliability prediction model for computers for space applications is developed in this paper. Significant redundancy is contemplated in order to achieve the desired reliability. It is noteworthy that this prediction model was used as a design tool, influencing where and how much redundancy was used. Apparently a sensitivity analysis involving straightforward perturbations was used rather than an optimal allocation approach. It is also noted that the model was programmed and used on a time-sharing computer system. As this is a rather specialized topic, the paper is for those with specific interests in similar computer systems.

R68-14045 ASQC 838

Joint Publications Research Service, Washington, D.C.

OPTIMIZATION OF THE RELIABILITY OF A REDUNDANT SYSTEM

L. K. Isayev and N. A. Mamed-Zade

In its Tech. Cybernetics No. 1, 1967 14 Apr. 1967 p 57–60 refs

(N67-24209)

A procedure is proposed for the solution of a problem with respect to determination of the maximum reliability of a reserved system with one restriction of the type of weight, cost or size. The proposed procedure is applicable for an increasing purpose function. Comparisons are made with other methods. Author

Review: A reader will need the references cited in this paper (all from Russian journals) in order to put the story together. The problem treated is a rather narrow one, essentially that of active redundancy reliability allocation with a single constraint. The essence of the paper is that the allocation obtained in two different problems treated in two of the references would be different if treated with an approach in another reference co-authored by the second author of this paper. There is no discussion of the reasons for the different allocations or of which is correct. Thus the paper is not highly self-contained and it is suspected that the effort to obtain the references and piece the story together would not be warranted. (A slightly different translation of this paper appears in Engineering Cybernetics, 1967, no. 1, p. 38–40.)

R68-14046 ASQC 838

Joint Publications Research Service, Washington, D.C.

A PROBLEM IN OPTIMAL REDUNDANCY

O. G. Alekseyev

In its Tech. Cybernetics No. 1, 1967 14 Apr. 1967 p 61–68 refs

(N67-24210)

The solution of the problem of optimal redundancy of an apparatus is investigated for several restrictions using the method of dynamic programming. For restriction of the search region, additional restrictions are introduced permitting significant decrease in the size of the computation operation and the requirements on the computer memory. Author

Review: The dynamic programming method is applied in this paper to the active redundancy allocation problem where two linear constraints are explicitly treated. Two inequalities are developed, which are used to narrow the region of search for the optimal solution. This appears to be a useful development. The approach is, of course, applicable to objective functions other than that concerned with active redundancy. Contents of the paper are mainly in functional notation and a numerical example is briefly sketched. (A slightly different translation of this paper appears in Engineering Cybernetics, 1967, no. 1, p. 41–45.)

R68-14047 ASQC 838

THE APPROXIMATE RELIABILITY OF TRIPLY REDUNDANT MAJORITY-VOTED SYSTEMS.

David K. Rubin (Jet Propulsion Laboratory, Pasadena, Calif.).

In: Digest of the Annual IEEE Computer Conference, 1st. Chicago, Ill., Sep. 6–8, 1967. Conference sponsored by the IEEE Computer Group with the cooperation of Northwestern University and the IEEE Chicago Section. New York, IEEE, Inc., 1967, p. 46–49. 7 refs.

Members, $4.00; nonmembers, $6.00.

An approximation method is proposed for determining the reliability of triply redundant majority-voted systems. Operational characteristics of the proposed method were studied by a generalized logic network; and reliability was determined by a summation of success probabilities and by minimal cut, Monte Carlo, and augmented block approximations. The method of augmented blocks, considered the preferred approximation, is reviewed for both simple series networks and for more complex logic interconnection patterns. This technique offers the advantage of about a 1000-fold increase in speed over other methods with little, if any, loss in accuracy. M.W.R.

Review: Potentially useful approximations of some rather specialized reliability logic models are presented in this well-illustrated paper. No specific systems are described, but this form of redundancy has been associated with digital computers. Anyone interested in reliability modeling should somehow take permanent note of the existence of this paper, as it constitutes useful reference material. The title defines the contents precisely.

R68-14049 ASQC 838; 821

RULES FOR APPLYING ERROR CORRECTING CODES TO COMPUTERS.

Herbert David Goldman (Hofstra University, Hempstead, N. Y.). *In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics.* New York, IEEE, Inc., 1967, p. 9–17.

Error correction coding is considered a more efficient means of improving computer reliability than is majority voting, although coding requires more design changes. "Coded alone" analysis indicated best reliability gains by using single error correction rather than multi-error correction codes. Multi-error codes should be used only in connection with majority voting; and, in terms of equipment spent, best reliability gains were obtained by a hybrid single error correction code combined with triplicated majority voting. Reliability gains are shown to be most effective when large memories are protected. An exponential mathematical model was used in the analysis; and three single error correcting Hamming codes as well as the application of triplicated majority voting in the large memory shift register of one of these codes were investigated. M.W.R.

Review: This paper does not contain any profound observations, nor indeed any that the interested and knowledgeable reader would not be able to make for himself. The claim for newness is that it deals with multierror correction, but the author deals with this in a very summary fashion. Since this paper is from a convention record, it is assumed that it was buttressed by an oral presentation—the style of the paper leaves much to the imagination, and some of the more important results are not supported. At the outset (Equation 1), the author defines reliability "gain" as the ratio of the probability of failure of the non-redundant system to that of the redundant system. However, when he defines the *ratio* of equipment complexity for the redundant system to that for the non-redundant system, he calls this equipment "size". This should be called "increase" for consistency. He further compounds this difficulty by calling this quantity "S" in some places, and "EC coded/EC uncoded" in others. It would also be desirable if he had set up some factor-of-merit, for example R/S. He talks loosely of this as a criterion for effectiveness, without spelling it out. The workmanship of the paper is bad to the point of being annoying in some places. An unfortunate typographical error at the top of the second column of the first page speaks of time (KH) when time (K+1) is intended. The first two tables are untitled (the remaining ones are titled.) In Table 7 the headings are reversed from those of Table 6, which at first glance leads to difficulty. The drawings are inadequately labelled. In Figures 4 and 5 the author resorts to black boxes, but he never says what they represent. The bibliography is both inadequate and inadequately referred to. The author should say, for example, where he gets the three Hamming codes, and also an additional reference or two would be good for both this and the theory of majority voters. It is interesting and unfortunate that the only values for which the calculations are actually shown are those for the simplest case, and yet this is the one in which the unexpected occurs—loss of reliability accompanies increased attempts to improve reliability. For the cases which support the author's conclusions, he merely presents the answers.

R68-14056 ASQC 837

THE PROBLEM OF REDUCING THE OUTPUT PARAMETER SPREADS IN ELECTRICAL AND ELECTRONIC CIRCUITS.

V. L. Bogunenko and Yu. S. Rasshcheplyayev

Telecommunications and Radio Engineering, Part 1—Telecommunications, no. 6, 1967 p 28–32. 2 refs.

An optimization method is described for reducing the output parameter dispersion in electric and electronic circuits. The constrained minimum of the dispersion of the function, with fixed expectation, is found; and then the optimal expectations of the component parameters are determined. A tunnel diode amplifier, which is very sensitive to component parameters, is used to illustrate the applicability of the proposed method. Output parameters were found to be more stable with optimal than with nonoptimal component parameter expectations. By optimizing the component parameter expectations, the operational stability of the circuit can be improved without increasing its design margins. An appendix details the means of computing the dispersion error due to linearization for two types of functions. M.W.R.

Review: The reduction of drift in the output of systems is an important part of design for high reliability and this paper makes a small contribution toward that end. The output is considered a function of several statistically independent variables. The functional relationship must be known and differentiable (linearization is required for tractability). The mean and variance of each of the parameters must be known, then the variance of the output is minimized under the constraint that the average output must stay the same. The problem then is solved insofar as the variance of the output is a measure of its deviations. It should be remembered that the variance is used extensively for this purpose more because of its tractability than because it is exactly the function that engineers are after. In optimization problems of this type the mathematical models being used are usually simple-minded at best and not all of the relevant factors have been taken into consideration. Therefore one may wish not to design at the indicated place but at some distance from it in order to optimize with respect to factors not in the original model. Since the solution for the original model is at a minimum point (generally this minimum will be fairly broad) one can operate at some distance from the optimum point without seriously impairing the optimized value. A classic example of this is found in the theorem of maximum power transfer. The load can be a factor of two times the optimum (matching) load with only 11% reduction in power, or three times the optimum load with only a 25% reduction in maximum power. In this case, for example, efficiency could be improved tremendously by operating at higher load resistances without much diminution in available power. The restriction of statistical independence is important since in most practical circuits, especially with regard to transistor parameters, the parameters can be very interdependent. Since the assumption of statistical independence comes in only in the variance of the output, the covariances can be taken into account without a great increase in complexity and with a consequent improved accuracy. If there is more than one output to be improved, the outputs can either be combined into a single figure of merit, or the separate optimum values of parameters can be calculated for each output and final values can be selected to be not too far from any of the calculated optimum values.

R68-14064 ASQC 831; 871

Army Electronics Labs., Fort Monmouth, N. J.

REPORT OF ECOM AD HOC GROUP ON MICROELECTRONIC ADP MAINTENANCE STUDY

11 Jul. 1966 24 p

(AD-664195; N68-87434)

Current state-of-the art is considered to have capability for microelectronic design for digital application with the exception of the memory and input–output devices of the computer. Self-diagnostic techniques indicate that more than 99% of the failures can be detected through a checkout program resident to the computer and requiring no more than 2 K memory. About 35 to 50% of the failures can be detected and isolated through a diagnostic program that requires from 10 to 12 K memory; and this program could be carried resident to the computer or externally and loaded as required. Failures can be diagnosed 90 to 95% of the time with additional built-in test logic that would require a 10 to 50% increase in machine size and weight. Additional test circuitry, either built-in or external, can result in diagnosis of the circuit board almost 100% of the time. Throw-away as well as evacuate and repair concepts are feasible to the board level. Design alternatives and their advantages, disadvantages, and priorities are listed for the various types of test equipment. M.W.R.

Review: This is a very brief report written in outline style, but it nevertheless contains a great deal of information, especially on the kinds of questions that need to be asked about a system. Some of the answers that were obtained have undoubtedly changed somewhat in the two years since the report was made, but these differences will not be significant for most people. The conclusions and recommendations tend to be much more specific than the questions and a few of them will probably have changed appreciably; however most of them will not. Since the ease with which a device can be maintained in the field contributes very heavily to its reliability (i.e., it works when you want it), this paper has useful information for designers and reliability engineers, especially those who are not specialists in this immediate area. The very surprising thing about the document is that it looks so thin to contain so many good points.

84 METHODS OF RELIABILITY ANALYSIS

R68-14021 ASQC 844; 782

Lockheed Missiles and Space Co., Huntsville, Ala. Research and Engineering Center.

STUDY OF THERMOELECTRIC COOLING OF ELECTRONIC EQUIPMENT Final Report

Jan. 1967 30 p

(Contract NAS8-18026)

(NASA-CR-61455; LMSC/HREC-A783745; N68-15786) CFSTI: HC $3.00/MF $0.65

The objectives of this study were threefold: investigation and test of thermoelectric coolers; the utilization of these thermoelectric elements in the cooling and temperature stabilization of electronic components; and the generation of a thermoelectric design manual. All the objectives have been achieved. Several thermoelectric coolers were chosen from different producers based on their heat transfer capacities, temperature differentials, coefficients of performance and sizes. These units were carefully tested and the data obtained compared with the manufacturer's published data. These tests showed clear performance differences among the producers of the thermoelectric elements. In general the quality of the units as measured by the coefficient of performance varied directly with the cost of the unit. An electronic mockup device for cooling electronic components was designed, fabricated, and tested. This unit performed as expected. A temperature stabilization chamber and a switching-type temperature control circuit were developed, designed, fabricated, and tested for a 0° to 100°C ambient temperature environment. The temperature inside the chamber was held to within 1.0°C of the initial setting (50°C). Author

Review: The main portion of this report is a set of instructions for applying thermoelectric cooling devices. Even though advances in the state of the art may change some of the numbers and break-even points listed, the principles will remain the same. Since proper temperature controls of equipment are essential in reliability-design, this paper can serve a useful purpose for design and reliability engineers. It is noteworthy that all of the thermoelectric devices tested were in need of reliability improvements themselves for any but benign environments.

R68-14024 ASQC 844

National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

STRESS CORROSION

Charles E. Cataldo

In its Res. Achievements Rev., Vol. 2 1966 p 7–14

(N67-29383)

This article recounts briefly some of the more critical stress–corrosion failures that have been experienced at Marshall Space Flight Center and the corrective action taken. Some of the recent stress–corrosion studies are described and preliminary results tabulated. Specific problems described are the H-1 Engine LOX dome, the pneumatic line fitting sleeve problems and the more recent problem with wave springs used on MF-flared tube fittings. The use of nitric oxide in preventing stress–corrosion failures in titanium tanks is also discussed. Author

Review: Case studies are valuable in two ways: (1) they graphically portray to the nonspecialist the need for concern in this area and (2) they transmit information about specific cases which may not be well known. But what can aerospace designers learn of general benefit from reading papers such as this? What kind of beforehand knowledge does it give them to enable them to prevent failures on the drawing board, rather than have them happen in the field? The designer has many calls upon his talents, and the myriad and multitude of ways in which metals, plastics, fabricated shapes, methods of treatment may involve failure tend to be extremely difficult to nail down beforehand. One of the things that can help in this regard is the compilation of authoritative tables which show all of the "strength" properties with, of course, some indication of areas in which no information is known or the information is less than certain. Once such compilations are available, it may be possible to put them in a computer program so that the insertion of a bill of materials will print out the problems that may arise in their use. In any event, something is needed to relieve the designer of the tedium of hunting for all this information and then applying it in detail. In papers such as this, it is easy for the novice not to remember that, when changing materials or heat treatment, one must go through the whole procedure again to make sure that no new difficulties have been introduced. This paper also shows the fact that changes made by a manufacturer to improve his product may not always be an improvement as far as a particular customer is concerned. Here again, unfortunately, the watchword for high reliability is "infinite attention to detail"

R68-14026 ASQC 844

FLOW LINES AND FORGING FAILURES.

Waldemar Naujoks 1966 Golden Gate Conference, San Francisco, Calif., Nov. 10–12, 1966, Paper. Metals Park, Ohio, American Society for Metals, [1966], 18 p.

(ASM Technical Report G6-1.6) Members, $1.50; nonmembers, $3.00

Methods and techniques to position metal flow lines in forged components are treated in terms of components used in

commercial, aircraft, and aerospace industries as well as for meeting the service requirements for the various components. The basis of grain flow or metal fiber structure is discussed; and it is noted that forgings in industrial and commercial uses generally tend to indicate the position of grain flow. Positioning flow lines in open die forgings is detailed, and mention is made of positioning in closed die forgings. Eleven sketches illustrate various aspects of positioning. M.W.R.

Review: The paper merely describes the pattern of flow lines due to solidification directions, working directions, and forging directions for commonplace components such as crankshafts, crane hooks, etc. The title of the paper specifically mentions forging failures, but there are no references or case histories to correlate flow lines to failures, an unfortunate omission for the reliability engineer. There is a reference to seventeen photographs (including a listing), but they are not included as a part of the paper. The paper does not present formal conclusions or recommendations. The beginner may want to use the paper for general reading, but a seasoned design engineer will obtain little or no benefit from it.

R68-14027 ASQC 844

MICRO AND MACRO MECHANISMS OF FRACTURE.

Earl R. Parker (California University, College of Engineering, Berkeley). 1966 Golden Gate Conference, San Francisco, Calif., Nov. 10–12, 1966, Paper. Metals Park, Ohio, American Society for Metals, [1966], 40 p. refs.

(ASM Technical Report GG6-1.7) Members, $1.50; nonmembers, $3.00

The nature of fracture processes is discussed in terms of plastic flow preceding the onset of fracture; and fracture is considered as composed of two stages, crack nucleation and crack growth. Tensile and cleavage fracture in ductile metals is treated; and strain rate and temperature effects are considered. The Griffith approach, equivalence of stress criteria for failure and energy release rates, and the plastic work form are discussed in relation to the behavior of notched bars and plates. Grain boundary failures at both elevated and low temperatures are noted, fatigue factor studies are viewed, and stress corrosion cracking is considered. Fractures associated with stress corrosion and notch brittleness are not understood from either a mechanical or micromechanical point of view, whereas the ductile shear-type failure and intergranular failure appear to be well understood. M.W.R.

Review: This paper reviews both the practical and the theoretical aspects of the many variations in fracture processes which the design engineer or the metallurgist may encounter. The paper is of current interest, but its scope is very broad. Any one aspect or type of fracture, i.e., fatigue, stress corrosion, etc., will be treated in greater detail elsewhere. The author, true to his position as an authority in the materials field and a renowned metallurgist, does an excellent job of relating the numerous fracture processes to the variable factors of stress state, strain rate, temperature, specimen geometry, and environment. The paper is well referenced and properly documented with graphical illustrations. Only one typographical error was detected. The mathematics of the paper was not checked in detail, but it appears to be correct.

R68-14028 ASQC 844

Mechanical Technology, Inc., Latham, N.Y.

REVIEW OF FAILURE MECHANISMS IN HIGHLY LOADED ROLLING AND SLIDING CONTACTS

A. J. Smalley, S. F. Murray, H. Christensen, and H. S. Cheng May 1967 70 p refs

(Contract N00014-66-C-0037)

(MTI-67TR23; AD-657337; N67-38115)

The failure modes of fatigue and scoring in highly loaded contacts are analyzed. Existing theories by which their onset may be predicted are critically examined, and the relationship between these failure modes and the phenomenon of elastohydrodynamic lubrication is shown. The possible modifying influence of microelastohydrodynamic occurrences is pointed out and a method of analyzing such occurrences is proposed. The protecting influence of boundary lubrication effects is also demonstrated, and mechanisms for satisfactory performance and failure under the influence of this phenomenon are put forward. Author (TAB)

Review: This document reviews fatigue and scoring failure modes which are associated with highly loaded rolling and sliding contacts. The paper is rather long, but it is composed of four completely independent sections dealing with elastohydrodynamic lubrication (fatigue and scoring failures); micro-elastohydrodynamic lubrication; and boundary lubrication. The organization of the paper, therefore, allows it to be read piecemeal without loss of continuity. The paper is recommended as a reference for design engineers, test engineers, and research engineers who are involved with bearing and gear application, design, and evaluation. The paper is well written (except for a few typographical errors which do not detract from its usefulness) and is properly referenced and documented. The mathematics of the paper was not checked in its entirety but it appears to be correct.

R68-14029 ASQC 844

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

SCATTERING OF ENERGY DURING VIBRATIONS OF ELASTIC SYSTEMS [K VOPROSU O SVYAZI RASSEYANIYA ENERGII V MATERIALS S USTALOSTNOY PROCHNOST'YU]

V. T. Troschenko 26 Apr. 1967 33 p refs Transl. into ENGLISH from Tr. Inst. Met. Akad. Nauk Ukr. SSR (Kiev), no. 4, 1963 p 149–158, 226–233.

(FTM-MT-65-231; AD-655019; N67-35677)

The chambers were operated at a combustion pressure of about 60 pounds per square inch absolute and propellant mixtures of about 12, 15, and 18 percent hydrogen by weight, yielding a nominal thrust level of 1000 pounds at sea-level conditions. The nozzle throat design diameter was 3.910 inches, and design contraction and expansion ratios were 1.897 and 3.679, respectively. The chambers were of cylindrical, right-conical construction, and the cooling system was such that the incoming fuel (hydrogen) was ducted in a jacket along the nozzle and combustion zone external surfaces from nozzle exit to injector in a single pass. Injectors used were of multielement coaxial design and had been developed to yield smooth high-performance operation with the thrust chambers used in this investigation. Local combustion gas-to-wall and wall-to-constant heat-transfer rates and coefficients as well as coolant pressure-loss characteristics were determined by data analysis. This information made possible the derivation of appropriate constants for modifications of a dimensionless heat-transfer correlation for local application. In addition, the coolant friction pressure-loss factors were compared with the values predicted by means of a familiar smooth-tube correlation. Author

Review: This is an edited machine translation from the Russian; it is difficult to read or understand because of incorrect words and unusual sentence structures. One of the important graphical illustrations is reproduced poorly. The chemical composition of the steels that were under test is not included in the paper; therefore, the general type of steel is not known, except for the Russian number designation. The author places greater emphasis on experimental apparatus than he does on the interpretation and

analysis of the data. Test engineers may find the description of the experimental apparatus useful. Metallurgists and design engineers may be interested in the author's conclusions.

R68-14030 ASQC 844; 720; 775

MICROELECTRIC WELDING—AN APPROACH TO IMPROVED RELIABILITY.

Stephen N. Bobo (Raytheon Co., Lexington, Mass.).
In: Electronic Packaging Conference, New York, Feb. 14–16, 1967, Proceedings. Conference sponsored by the Society of Automotive Engineers New York, Society of Automotive Engineers, Inc., 1967, p. 6–12.
(A67-38620)

Description of a technique of IR monitoring to improve the accuracy of the diagnoses of welding inspectors. The technique uses a prototype welder, which is a modified parallel gap welder using a voltage feedback to regulate the output during the welding process. An experimental program verified that IR can be useful, not only in welding control, but as an extremely good monitor of weld quality without the necessity of using it to control. The concept of IR monitoring can be extrapolated into structural welding for purposes of continuous 100% quality determination, control, flaw detection, etc. IAA

Review: The main useful message of this paper is that the magnitude of the infrared emitted from the metal junction during a weld can be used to monitor the quality of the weld. There are several characteristics of this system that are important. (1) The system responds only to the short-wave-length tail of the radiation, so that it is probably much more sensitive to changes in temperature than to amounts of radiation at the given temperature. (2) Fiber-optics are used for the optical system and thus allow the weld to be monitored very closely without bulky lenses and without other interferences in the optical path. While it is stated that infrared response is used to monitor the quality, there is no specific indication of how the operator uses it: whether a peak value is read from an oscilloscope, whether there is automatic monitoring, whether it is combined with the voltage measured on the oscilloscope, or what? There are some typing errors in the discussion of the simple theory plus the fact that the symbol E is used for both voltage and emissivity. This turns out not to be important since the algebra is used only to establish that the power emitted is a function of the electrode voltage and the weld-junction temperature. It should be noted that this is not an after-the-fact assessment of the weld but an assessment during the weld itself. This has advantages for quality control of manufacture but does not help any during inspection. Since determining the quality of welds is an important problem in aerospace electronics, this paper does provide a service in showing an extension of the state-of-the-art. The author has indicated in a private communication that further information is available to interested readers who may wish to write him.

R68-14031 ASQC 844

THE PROCESS ORIGIN OF IMPURITIES IN HERMETIC ELECTRONIC DEVICE PACKAGES.

P. H. Eisenberg and G. V. Brandewie (North American Aviation, Inc., Autonetics Div., Anaheim, Calif.).
In: Electronic Packaging Conference, New York, Feb. 14–16, 1967, Proceedings. Conference sponsored by the Society of Automotive Engineers New York, Society of Automotive Engineers, Inc., 1967, p. 135–143. 7 refs.
(A67-38632)

Investigation of the process origins of gases and contaminants in hermetic electronic devices. The techniques used by various manufacturers to make hermetic packages were compared for common practices associated with the closure techniques, the ambients, temperature, and their controls. These were evaluated and compared with the analyses performed using mass spectrographic and gas chromatographic techniques. The results obtained indicated the major sources of impurities to be: (1) dry box ambients, (2) outgassing for metal surfaces, (3) residual processing solvents, and (4) weld flash, etc. Examples of corrective actions which eliminated these process-oriented impurities are described. For instance, open aluminum interconnects in integrated circuits were determined to be caused by chloride corrosion present as a result of incomplete cleaning processes. IAA

Review: This paper is another example of reliability's being characterized by infinite attention to detail. In this case, the detail is the origin of impurities which are sealed into the hermetic package and the ways they can get in there. Studies of this kind are important for many applications. The case histories are helpful in that they may provide the graphic motivation for designers and reliability engineers to recognize a problem and to do something about it. Perhaps an even more important purpose served by this kind of paper (and this paper in particular) is to put in perspective the "management type" papers presented by various manufacturers. The papers by manufacturers tend to be glowing accounts of the tremendous efficiency and accuracy with which their production lines are run, and the tremendously super-high quality and reliability that goes out their doors. While these papers are well-intentioned and no doubt describe the way management wants the operation to proceed, in actual fact life is usually somewhat more complicated. It is these complications that are discussed in the paper and which are so important to reliability engineers and to designers who are charged with the responsibility for very high reliability.

R68-14032 ASQC 844; 831; 836

FAILURE MODE AND EFFECT ANALYSIS: AN AID TO INTERPRETATION OF CRITICAL ELEMENTS IN SYSTEM DESIGN.

Harry E. Arnzen (Grumman Aircraft Engineering Corp., Bethpage, N.Y.).
In: Transactions of 1967 Spring Product Assurance Conference and Technical Exhibit, Long Island, N.Y., Apr. 15, 1967. Conference sponsored by the American Society for Quality Control, the Standards Engineers Society, and the Society of American Value Engineers, Arno Press, Inc., [1967], p. 93–109. 11 refs.

Formats for preparation, contents, and applications of Failure Mode and Effect Analysis (FMEA) are considered in relation to system design evaluation and reliability improvement. Typical aircraft flight control and manned spacecraft attitude control systems are used to illustrate the application of a simplified functional FMEA; and design review procedures as well as system improvements resulting from the FMEA are tabulated for each system. Preparation of a vendor FMEA for product design is described, and a sample FMEA for a propellant tank is shown. Also noted is the preparation of a final complete system or subsystem FMEA for use in the production design stage. The general sequence of tasks involved in all three types of FMEA's is detailed, and the role of the FMEA regarding decisions for redundancy in catastrophic failures is considered. In addition to its reliability engineering role, the FMEA is considered a useful tool for technical support, quality control, training, and simulation groups involved in a vehicle development program. Use of the FMEA in conjunction with design reviews development can avoid costly modification by indicating latent defiencies in designs as well as potentially hazardous conditions. M.W.R.

Review: This paper is the same as the one covered by R67-12939.

R68-14036 ASQC 844; 775
FAILURE ANALYSIS—A TOOL FOR IMPROVING PARTS.
Lloyd W. Garrand (Airborne Instruments Lab., Reliability Dept., Mineola, N. Y.).
In: Transactions of 1967 Spring Product Assurance Conference and Technical Exhibit, Long Island, N. Y., Apr. 15, 1967. Conference sponsored by the American Society for Quality Control, the Standards Engineers Society, and the Society of American Value Engineers. Arno Press, Inc., [1967], p. 149–164.

Seven techniques for performing failure analyses are discussed, and some examples of each are included. Visual inspection, X-ray examination, microscopy, infrared radiation scanning, radio frequency probing, hermeticity testing, and polarized light photography are considered. The need for failure verification is stressed. M.W.R.

Review: A readable overview of the operation of a failure analysis laboratory for an electronic equipment producer is given in this paper. The scope of the techniques which are cited is broad enough to provide some ideas for increasing the capabilities for those with less sophisticated operations. Some such techniques are r.f. probe, infrared radiation, polarized light photography, and the use of fast-developing X-ray film. While these are not unique to this laboratory, it is reasonable to suppose that many failure analysis laboratories are not making use of them. The paper is illustrated with many "horror" photographs, which would have been more effective if the failure features in them had been highlighted. (The author in a private communication has indicated that this highlighting was done with slides in his verbal presentation, but the emphasis does not appear in the printed paper.)

R68-14040 ASQC 844; 833
SUPERALLOY CASTINGS ARE MEETING SMALL-TURBINE BLADE LIFE NEEDS.
SAE Journal, vol. 76, Jun. 1966, p. 51, 52.

Integral castings of nickel superalloy are considered the best compromise between costs and life expectancy in automotive and small industrial turbine blades. Both fatigue strength and corrosion resistance requirements can be met by these superalloys, and the use of protective coatings is increasing to meet the hot strength corrosion resistance requirements. A general review of materials used to meet these requirements is included; and it is noted that turbine wheel temperatures may soon exceed the limits of nickel superalloys and that ceramic materials can offer the necessary properties to meet these higher temperatures. M.W.R.

Review: This paper is a good short summary of some of the problems involved with turbine blades, but the title and subtitle do not necessarily reflect the content of the paper. Even though it is a summary of a panel session, none of the controversy that one would like to think exists in a good panel session is brought out. (If there is no controversy, what is the point of having a panel as opposed to several papers on the subject?) One of the things the article shows by implication is that engineers are always going to be pushing the state of the art, because as soon as they solve a set of problems (in the automotive turbine, for example) they are pushed, due to the pressures for efficiency and economy of operation and construction, to make new assaults on the state of the art.

R68-14051 ASQC 844; 775
X-RAY VIDICON ANALYSIS OF MICROELECTRONIC DEVICES.
Harvey F. Padden and John J. Lombardi, Jr. (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).
In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 26–32.
(A68-11669)

Discussion of X-ray vidicon analysis as a means of nondestructive testing of microelectronic devices. Advantages offered by vidicon-tube detection over photographic plate detection are discussed, and a series of photographs of microelectronic defects which were detected by vidicon analysis is presented. IAA

Review: This paper describes a technique for the screening of microelectronic devices which, cost factors aside, appears to have relevance to high microcircuit reliability by eliminating many of the mechanical defects that appear in such devices. The paper is largely given over to sample radiographs which show certain kinds of defects. A specification was also prepared for testing incoming devices. Reliability and quality control engineers certainly should be familiar with this technique, and this paper can provide part of that familiarity. The problem of cost is not discussed, and this information will have to be obtained elsewhere.

R68-14053 ASQC 844; 775
AUTOMATED TROUBLESHOOTER WORKS ON INFRARED SIGNATURES.
J. Fred Stoddard and Riccardo Vanzetti (Raytheon Co., Wayland, Mass.).
In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 65–77.

A fully automated infrared "compare system" for measuring power dissipation of electronic components is described. Especially designed for use in a manufacturing operation, the infrared testing can be inserted in the normal production cycle and save time and costs and increase reliability and life expectancy of the equipment. The concept of infrared signature is discussed, specifications for the infrared equipment are given, and the compare system is outlined. Essentially, this system measures radiometrically the temperature of individual electronic components on a printed circuit card while the circuit is in operation, temporarily stores this temperature information, and then matches it with previously stored patterns. Powering of panels on the continuous feed table, programming, and analog and digital interpretation are considered. Some operating results for the technique are included, and its applications and costs are discussed. M.W.R.

Review: The authors are quite understandably enthusiastic about the system they have developed, and they have written the paper in a very positive vein. The system does apparently do a great many things much more effectively than other inspection systems can. This type of testing can make important contributions to high reliability. The limitations and practical manifestations of the actual system appear only later in the paper, so that the reader who thought that a 23 × 23 mm area was being everywhere analyzed to a resolution of 0.2 × 0.2 mm (an area ratio of approximately 200 to 1) and compared with a reference over the entire area in a fraction of a second will find later that this is not so. It is not that the system does not do many good things. It is just that the advance billing is somewhat exuberant. No indication is given of (a) how temperature differences are calculated when the emissivities are unknown, (b) whether the allowable limits of deviation are set on a percentage basis or an absolute deviation basis, and (c) whether the deviation limits are set by some algorithm on the computer or whether they are set by hand after observing the data. These remarks should not be construed as deprecating the system that has been developed since it apparently

does a great deal that needs to be done in the field of electronic reliability. It is not too difficult, however, to envision cases of electronic equipment wherein the proposed system is not the answer to systems checkout. No details of the system are given as compared to, for example, the description in the paper by Peterman and Workman which immediately follows this one in the same volume.

R68-14054 ASQC 844; 775
INFRA-RED RADIOMETRY OF SEMICONDUCTOR DEVICES.
David Peterman and Wilton Workman (Texas Instruments, Inc., Dallas, Tex.).
(Microelectronics and Reliability, vol. 6, Nov. 1967, p. 307–315. 6 refs.) In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 78–86. 6 refs.
(A68-15586)

Study showing that IR radiation can be used to measure the local surface temperature of semiconductor devices, provided that the emissivity is known. This measurement involves optical systems that collect radiant energy and focus it onto a suitable detector from which an electric signal is amplified and displayed. IR radiometry can provide indirect measurement of local temperature as an important variable in the design, testing, and analysis of semiconductor devices. This is especially important in the die layout of an integrated circuit, since many circuit designs depend upon matched parameters of their individual transistors. Design problems involving thermophysical characteristics of fixed-spot radiometers, emissivity control coatings, fixed-beam radiometers, and scanning radiometers are discussed in relation to the information gained from IR radiometry. IAA

Review: This paper deals with the use of infrared radiation from silicon wafers and chips rather than in finished electronic circuits. Thus, the problems being discussed are quite different from those in the paper by Stoddard and Vanzetti which immediately precedes this one in the same volume. This paper gives a good discussion of the general instrumentation and its properties, together with the kinds of things it can measure on the silicon die. Infrared measurements are not claimed here to be the final solution to all of the problems (as they are in some articles); but they are shown to be a very useful tool and to give answers that are not readily obtainable otherwise.

R68-14055 ASQC 844; 775
INFRARED PINPOINTS SECOND BREAKDOWN BEFORE FAILURE.
M. F. Nowakowski and F. A. Laracuente (NASA, Marshall Space Flight Center, Huntsville, Ala.).
In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967. 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 87–94.
(A68-11670)

Description of a high-resolution IR microscope used to detect and analyze second breakdown in transistors, and phenomenon caused by extreme current concentration at the collector junction. The test procedure used to determine the location, size, and temperature of the breakdown area is outlined. IAA

Review: The subject of this paper is the fast-scan infrared microscope, a tool whose potential has been examined previously (see R67-13505). The application considered here is the identification of second breakdown sites prior to actually observing second breakdown. The authors suggest that the fast-scan infrared microscope can be used in production to screen units which are prone to second breakdown from the more resistant units. Such a possibility does seem quite reasonable based on the evidence given in the paper. The concept of hot spots developing at discrete sites during second breakdown is confirmed by this new tool with hitherto-unattainable spatial precision. In spite of the author's claims that "a detailed analysis of the 'hot spot(s)' was performed in an effort to determine why second breakdown occurred there and not in some other location," little insight into the second breakdown phenomenon emerges; no new answers to old second breakdown problems are provided. The infrared microscope would seem to be a very useful tool, however, for developing such answers. Inexplicably the authors describe 1300°C as the approximate melting temperature of bulk silicon. 1427°C is the commonly-listed value and can be substituted for 1300°C in the text (two places) without otherwise changing its meaning.

R68-14059 ASQC 844
REALISTIC PHYSICAL TESTING.
S. Roy Swanson (MTS Systems Corp., Edina, Minn.).
Industrial Research, June 1968, p. 84–88.

An overall historical review of physical testing techniques is presented, and the extreme optimism of early quality control people is noted along with the trend toward more realistic physical testing in present-day industrial practice. The fact that catastrophic failures occur in aircraft, automobiles, bridges, pipelines, spacecraft, and manufactured items has stressed that some of the older physical testing methods have not always provided results that are applicable to actual operating conditions. Attention is given to safety considerations in product development, and the many aspects of fatigue damage and its prediction are discussed. Some experiences with both hard and soft systems are reported, and the uniting of the testing machine with the computer is considered the overshadowing factor in increasing the capabilities of physical testing in industry. M.W.R.

Review: This paper deals with fatigue testing of metals rather than with the general subject of physical testing; and, ignoring the philosophical and metaphysical seasoning of the paper, it does a good job of discussing the disadvantages of (a) the old-fashioned SN curve combined with various Goodman diagrams and (b) various theories of cumulative damage. The paper concentrates mostly on deprecating the earlier methods of fatigue testing rather than showing exactly how it should be done. That there have been structural failures in the past is obvious, but these do not always stem from the lack of adequate testing of the material's properties. There are many things we do not know about structures, not the least of these being the actual stresses in the materials at every place, plus the fact that simple fatigue often does not occur but there is fretting fatigue, stress corrosion fatigue, etc. Good designers and a great majority of all designers are only too painfully aware of the inadequate knowledge they have in the fatigue area, but even more realistic testing of structures will not give the entire answer. This paper will serve the most value for managers and uninformed designers to bring them up to data on what is good and what is bad with fatigue testing of metals. Considering the magazine in which the article appears, that is perhaps the level on which it was written.

R68-14060 ASQC 844
STRUCTURAL DEFECTS IN EPITAXIAL $GaAs_{1-x}P_x$.
Forrest V. Williams (Monsanto Co., Central Research Dept., St. Louis, Mo.).
AIME, Transactions, vol. 239, May 1967, p. 702–705. 6 refs.

The dislocation and stacking-fault structure of epitaxial $GaAs_{1-x}P_x$ has been examined by chemical etching. The layers

were grown in the ⟨100⟩ direction and etch pits were developed on {111} planes which had been lapped and polished on the epitaxial layers. The effect of the following variables on the quality of the epitaxial layers has been examined: doping level, growth rate, and composition. High stacking-fault densities were found in the $GaAs_{1-x}P_x$ layers. These are not observed in heavily doped epitaxial layers nor in layers with low phosphorus compositions. The dislocation density in $GaAs_{1-x}P_x$ was highest at the substrate-epitaxial layer interface. Composition changes introduced dislocations in the epitaxial layers. Author (IAA)

Review: Epitaxial $GaAs_{1-x}P_x$ layers exhibit greater dislocation and stacking fault densities than the GaAs substrates on which they are grown. This brief paper suggests that growth rate, doping level, and defect density are interrelated. Little explanation is offered as to why; the paper is primarily a report of observations. The statement is made that the higher dislocation densities of the $GaAs_{1-x}P_x$ layer differ from those of the substrate primarily in distribution rather than in absolute number. The figures make the absolute number look much higher as well.

R68-14063 ASQC 844; 821

National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

STRUCTURAL OPTIMIZATION WITH PROBABILITY OF FAILURE CONSTRAINT

Dhanjoo N. Ghista Washington, NASA, Dec. 1966 17 p refs (NASA-TN-D-3777; N67-13720) CFSTI: HC$3.00/MF$0.65

The concept of probability of failure is explained for a general structural system under simultaneous and alternative load systems. It is then shown how the probability of failure constraint can be formulated in terms of the structural design parameters. This constraint is developed in detail for optimizing a simple truss whose design parameters are the section areas of the members. The optimizing weight function and the constraint in terms of the design parameters define the mathematical model of the structural optimization problem. The structural synthesis method is suggested for solving the mathematical programming problem, and it is shown how the probability of failure constraint can be incorporated in the synthesis technique. The application of the constraint is illustrated by means of two simple examples with reference to the truss. Author

Review: This paper attempts to show how to calculate the probability of failure of a structure when the distributions of loads and strengths are known, but does not go deeply enough into the subject. There are major difficulties which render the treatment virtually worthless. These stem, in part, from (1) using shorthand probability notations (and thus the writer manages to confuse himself) and (2) the lack of appreciation of the technicalities involved in statistical independence. 1. Equations 1 and 13 (which are the same) are incorrect. It is instructive to write the equation using good probability notation and careful definition of the events involved. Let $q_i \equiv$ event of failure due to load $Q_i (i = 1,2)$. Then $Pr(q_1 + q_2) = Pr(q_1) + Pr(q_2) - Pr(q_1 \cdot q_2)$. Note that (a) there is nothing in the formula about applying both loads together; and (b) it is not even obvious that the events q_1 and q_2 are statistically independent. To illustrate the fallacy of thinking that the formula can actually combine failures due to both loads together: Suppose that Q_1 and Q_2 are equal and opposite; obviously then the system cannot fail under the application of both loads since the net load is zero. It is worth noting that the author states "...two loadings, Q_1 and Q_2, which may or may not occur simultaneously." This makes his Equations 1 and 13 all the more wrong. 2. Equation 2 assumes that the failures of the elements are statistically independent. This is an extremely restrictive assumption since while the strengths of the members may well be statistically independent (and in the text-example they are not, since they are stated to be the same), the stresses are not; in fact, given the stress in one member, it is possible to calculate exactly the stress in another. This equation is sufficiently restrictive so that it nullifies the conclusions of the paper and it should not be used in this kind of analysis without careful consideration and explicit verification of its validity. It is worthwhile pursuing the author's treatment in more detail to show just where the assumption falls down. In Equation 7 the author presumes that the strengths of all members are the same, albeit that strength is a random variable. Presume for the moment that there is but one load being applied to the system. Then the stress in any particular member is equal to the load times the geometry factor for that member. Let S^* be strength, C_i the geometry factor for the i^{th} member, and Q the load applied to the system. Then the exceedance of strength over stress is $g_i \equiv S^* - C_i Q$ for the i^{th} member. Presume that S^* and Q are statistically independent. Then it can be shown that $cov(g_1, g_2) = var(S^*) - (C_1 + C_2)\ cov(S^*, Q) + C_1C_2\ var(Q) = var(S^*) + C_1C_2\ var(Q)$; var = variance; cov = covariance. In this situation it is extremely unlikely that the covariance of g_1 and g_2 will be zero. If the covariance is not zero, g_1 and g_2 cannot be statistically independent. Therefore, the author's Equation 2 would have to be modified. It is possible to solve this problem; but the author has not done it. A minor difficulty in the paper compared to the other difficulties is that there is no indication (other than being $\pm 6\sigma$ for the Normal distribution) where the probability of 0.987×10^{-9} (for highest load and for minimum strength) came from; naturally this probability corresponds to a much stronger design than a 1% probability of failure. Just why this particular probability of 10^{-9} was picked as being approximately zero rather than, say 10^{-3} or 10^{-15}, is not clear. Nor is it obvious exactly what this particular example is intended to prove; obviously a 10^{-9} probability of failure requires stronger design than a 20% or 1% probability of failure. In the structural field a 1% chance of failure is a relatively large risk. No mention is made of any time periods over which these probabilities of failure are likely to occur. In conclusion, one should not use this paper at all, but should get information on the subject elsewhere.

R68-14066 ASQC 844

FAILURE MECHANISMS AND DEVICE RELIABILITY.

J. S. Smith and J. Vaccaro (USAF Systems Command, Research and Technology Div., Rome Air Development Center, Griffiss AFB, N. Y.).

In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6-8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 1-9. (A68-27237)

The paper shows how expressions for failure mechanisms may be derived and related to device reliability. The necessary conditions and limitations of such relations are examined, and their applicability to practical device reliability problems is assessed. The role of the reliability physicist in furnishing needed information and understanding at the mechanism level is indicated. Author (IAA)

Review: This paper provides a good summary of many of the difficulties encountered in attempting to relate device reliability to failure mechanisms and presents some sound guidelines for reliability physics investigations. For tractability purposes, detailed analytical expressions relating reliability parameters to basic properties of the device material are usually limited in practice to the simplest situations. For example, one might use only a single mechanism and assume linear degradation with time. As noted in the paper, such expressions have been found more useful in studying device behavior and in serving as a guide to design, test, and application of devices than in predicting device failure rates.

The complexity of the relationships in the more realistic cases involving multiple mechanisms has traditionally precluded developing analytical models with any meaningful detail. A simple modeling approach based on qualitatively cataloging types of failures is described in the paper; average time to failure for a device is expressed as a weighted sum of average times for different categories of failure. Unfortunately, the algebraic formulation for determining the average time to failure for each category is not clear—due to poorly defined notation and assumptions. A general criticism is that much of the mathematics is either trivial statements or detailed physical analysis of some extremely simple model wherein the exact details have little bearing on the discussion. The other portions of the paper are useful, however, and can aid reliability managers and novices in reliability physics in gaining an appreciation of the many problems in this field.

R68-14069 ASQC 844; 835

THE EFFECT OF CLEANLINESS ON INTEGRATED CIRCUIT RELIABILITY.

D. L. Cannon and O. D. Trapp (Westinghouse Electric Corp., Molecular Electronics Div., Elkridge, Md.).

In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 68–79

Deionized water, trichloroethylene (TCE), and isopropyl alcohol (IPA) were studied as cleaning solvents for integrated circuits, and a conductivity decay trace test was found to be an effective measurement tool for determining ionic contamination levels due to solvents. While organic solvents appeared to clean the integrated circuits effectively, such solvents did leave ionic contamination. If used improperly, TCE can have bad effects on circuit stability. It is advised that the use of TCE followed by an IPA rinse should also include a nitrogen lidding ambient and a final clean rinse with deionized water. The presence of organic oils should be avoided during cleaning procedures. M.W.R.

Review: The authors have assessed the ionic contamination of various electronic-grade solvents by cleaning test parts with these solvents, immersing them in a test cell containing standard deionized water, and measuring the rate of change of resistivity of the water. Deionized water itself shows up as best—in substantial agreement with industry practice. This paper is of interest as a reference containing quantitative comparative data for several common cleaning solvents. The superiority of deionized water as a final cleaning rinse in silicon processing is not a new finding but convincing data to substantiate this opinion has been elusive in the literature. The title may be misleading—the relationship between ionic contamination and integrated circuit reliability is assumed to be known.

R68-14070 ASQC 844; 835

SILICON NITRIDE PASSIVATED INTEGRATED CIRCUITS—RELIABILITY IMPROVEMENTS.

O. D. Trapp and J. B. Preece (Westinghouse Electric Corp., Molecular Electronics Div., Elkridge, Md.).

In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 96–105. 14 refs.

Silicon nitride passivated integrated circuits exhibited exceptional stability to inversion after reverse bias accelerated stressing up to 1000 hr at 175°C, and the limiting factor to device stability was found to be the mobile ion cleanliness of the silicon dioxide interlayer. Several oxide-nitride structures compatible with large scale manufacturing were investigated. The method used to transfer the process technology from the laboratory to the production line was one of evolving an optimum process by repeating with small variations statistically designed experiments or process cycles. The critical steps of silver nitride deposition and etching were transferred in increments from the laboratory. Two experimental designs to establish the reliability of the process are reported; and the process of removing the thermal oxide and depositing the silicon oxide appeared to be indistinguishable from each other or other groups which were failure free and very stable. These results indicated that thermal oxides prepared in conventional hot diffusion furnaces have a very limited number of mobile ions when the top silicon dioxide layer is removed and are not the limiting factor in device stability. M.W.R.

Review: Three important contributions of this paper are: (1) a comparison of oxide passivated structures with oxide-nitride passivated structures, demonstrating the superior stability of the latter; (2) evidence to suggest that the nitride layer is a barrier to alkali ion motion but *not* a getter; (3) the conclusion that mobile ions do not limit device stability when the oxide is thermally grown in a conventional hot diffusion furnace and has its top layer stripped off before nitride deposition. In general, device stability is determined by the ionic content of the oxide layer; the third conclusion says that this limitation has been overcome. In a subsequent private communication the authors have indicated that this third conclusion is true only when the etched oxide surface is sealed with silicon nitride. The language used in the paper does not clearly include the nitride layer and the reader may infer the more powerful general conclusion as stated above. The description is brief and the conclusions must be accepted largely on faith. Thus the paper is a summary of findings rather than an exhaustive proof of basic properties. The comments concerning technology transfer from the research laboratory to the production line distract from the main thesis. (In Fig. 5 input diode 4 is mislabeled 7.)

R68-14071 ASQC 844; 775; 851

THERMOPHYSICS OF RELIABILITY SCREENING.

H. R. Plumlee and D. A. Peterman (Texas Instruments, Inc., Dallas, Tex.).

In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 108–113. 5 refs

(A68-27243)

Discussion of some of the complexities of the thermal behavior of transistors and its relationship to reliability screening data. A comparison is made between the results of measuring thermal impedance by various electrical methods and by using an IR microradiometer method. It is concluded that many modes of failure can be characterized more accurately by using a multiparameter analysis of reliability test data. IAA

Review: This title is rather grandiose for the paper. Basically the paper discusses a few of the problems in trying to measure the junction temperature of transistors and pointing out that the term junction-temperature is itself a misnomer since the entire junction is not at a uniform temperature. For those who are not acquainted with this situation, this paper provides an introduction to the problem. It does little else however, except that some results are given for illustration. (While it is pointed out in the paper that the thermal impedance varies with operating conditions, the

author in one place suggests using it as a standard. If it is appropriate as a standard, then those particular parts are poorly written.)

R68-14073 ASQC 844
METALLIZATION AND BONDS—A REVIEW OF FAILURE MECHANISMS.
G. L. Schnable and R. S. Keen (Philco-Ford Corp., Microelectronics Div., Blue Bell, Pa.).
In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 170–192. 142 refs.
(A68-27247)

Review of materials and techniques used for metallization and bonding of silicon devices, particularly integrated circuits. Available data on the reliability of various structures and on failure mechanisms are discussed. Metallization systems considered include Al, Mo-Au, and Ti-Pt-Au. Bonding methods considered include thermocompression and ultrasonic wire bonding, and facedown bonding and soldering techniques. Metallization and bond failures are the principal modes of failure in integrated circuits. It is predicted that Al will continue to be the most widely used metallization system, with an increasing usage of ultrasonic bonding and face-down bonding techniques. IAA

Review: This paper is a good review of metallization and bonding methods for silicon devices along with the problems of each. The reference list is exhaustive, containing 142 entries, the latest of which are dated Nov. 1967. Aluminum metallization failures are well illustrated. The exposition is clear, if somewhat repetitive in places, and does summarize the state-of-the-art with insight. The classification of failures into metallization failures and bonding failures, the separation of failure causes into manufacturing defects and inherent limitations, and other general taxonomy give the reader a grasp of the subject that would be hard to acquire by plunging directly into the voluminous literature, each paper of which is most often directed to only one segment of the entire spectrum. The authors have succeeded in fitting many diverse bits of work together to give a fair description of the entire spectrum. Of particular interest are the figures comparing failure causes within rated operation with those under operation at levels far in excess of the maximum ratings. The first sentence of the conclusions section, which means that no one metallization and bonding system is more reliable than any other, could be misread to mean something quite different.

R68-14074 ASQC 844
FAILURE MECHANISMS IN INTEGRATED CIRCUIT INTERCONNECT SYSTEMS.
Bernard Selikson (Lowell Technological Institute, Lowell, Mass.). *In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings.* Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 201–208 25 refs.

Intermetallic compound formation was found in aluminum-gold systems, platinum-titanium-gold beam lead systems, and all of the systems except aluminum proposed or presently used as interconnect systems in integrated circuits. The all aluminum system is simple and also free of critical deposition thickness, variable residual oxide in the window, interdiffusion, and void formation. Because bond opening is the principal failure mode in semiconductor devices, a study was made of silicon nonplanar transistors using aluminum metallization with different bond wires. Rapid bond degradation occurred at the silicon in gold wire bonded units; and an all aluminum or all gold system was suggested as the solution for the purple plague and other compound formation problems in semiconductor interconnect systems. Contact metal-overlay metal systems currently in use in integrated circuits, aimed at overcoming the gold-aluminum purple plague compound formation, are discussed: (1) aluminum contact, silver overlay; (2) aluminum contact, chromium overlay covered with gold; (3) aluminum, then molybdenum contact, gold overlay metal; (4) molybdenum contact, gold overlay; and (5) platinum silicide contact, and titanium-platinum-gold overlay. M.W.R.

Review: This paper is a rapid review of the metallization problems that have plagued the semiconductor industry, as reported in the literature of the past five years or more. All significant developments are mentioned, at least briefly, and a well-organized, unified description of the problem and its present status emerges. This unity is not apparent in all treatments of this problem; most authors discuss one viewpoint to the exclusion of others. This is not to say that the author is subordinating his own work. Not at all. He considers the catalytic role of silicon to be as important as ever and restates the conclusions of his earlier work. The suggestion was made in a review of one of the author's previous publications (see R64-11508) that gold wire bonds to aluminum pads on top of silicon oxide might free the gold-aluminum bond from the catalytic effects of silicon. This paper reports that this is not true; the aluminum reacts with the silicon oxide to produce *sufficient silicon to permit the catalysis to proceed as before.* The prime message of the paper is that the all-aluminum metallization system (aluminum contacts, intraconnects, bonding pads and wires) is simple and performs well. Multi-layered metallization schemes are more difficult and, in many combinations, subject to intermetallic compound formation which can degrade the contact in a manner similar to the well-documented degradation of gold-aluminum contacts.

R68-14075 ASQC 844
MECHANISMS OF CONTACT FAILURE IN SEMICONDUCTOR DEVICES.
R. S. Keen, L. R. Loewenstern, and G. L. Schnable (Philco-Ford Corp., Microelectronics Div., Blue Bell, Pa.).
In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles., Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 216–233. 57 refs.
(Contracts AF 30(602)-3610; AF 30(602)-4034)
(A68-27250)

Study of the mechanisms of failure in ohmic and expanded contacts, including metal-semiconductor contacts and bonds to metallization in semiconductor devices. The study indicates that, within a number of systems, degradation or catastrophic failure has been produced by diffusion which produces solid solutions and/or compound formation. Means for studying interactions in ohmic contacts are considered, and it is concluded that the measurement of electrical resistance and resistivity change of thin-film structures is an effective method for obtaining data about degradation processes in ohmic contact structures subjected to various elevated temperatures. IAA

Review: This paper is a follow-on to previous publications of the same experiment (see, for example, R67-12932). The thin film structure is reaffirmed as a useful structure for studying

metal-metal interaction kinetics. The paper presents more data on specific systems, particularly Au–Cr, Ni–Cr, Au–Ti, Ti–Al–Si and Al–Ta in addition to the previously discussed Au–Al and Al–Si systems. An increased emphasis on diffusion effects only—no intermetallic compound formation required—appears here, confirming the work of Chen (see R68-13876). A phenomenon called K-state formation (film resistivity increases, decreases, and then increases with time at temperature) is also introduced to the interpretation of the results. This work, represented by this paper and its predecessors, continues to be a major source of information on the reliability and performance of metallization combinations for silicon devices. In light of the many reported deleterious interactions that plague most multi-metal systems, the simple, all-aluminum metallization system that is most frequently used in today's silicon devices appears more attractive than ever.

R68-14076 ASQC 844

FACTORS AFFECTING THE RELIABILITY OF WET TANTALUM CAPACITORS.

W. M. Rowe and P. H. Eisenberg (North American Rockwell Corp., Autonetics Div., Anaheim, Calif.).

In: Institute of Electrical and Electronics Engineers, Annual Reliability Physics Symposium, 6th, Los Angeles, Calif., November 6–8, 1967, Proceedings. Symposium sponsored by the Electron Devices Group and the Reliability Group of the Institute of Electrical and Electronics Engineers. New York, IEEE, Inc., 1968, p. 243–255.

(A68-27252)

Discussion of some of the factors affecting the reliability of wet tantalum capacitors (also called "wet slugs") in high-reliability circuit applications. It is shown that a feasible oxide integrity screen can detect those anode slugs that are imperfect before they are placed within the confines of their packages. The various behavior characteristics of these capacitors are briefly described, and a definitive test program designed and initiated to resolve their causes and to establish suitable corrective action is discussed. IAA

Review: This is one of the few non-semiconductor-device papers presented at this Symposium and illustrates the level of detail to which one must often go in trying to improve the reliability of a particular device. Anyone who is interested in wet tantalum capacitors per se will of course find the paper of value. Others will be interested in it only as an example of a comprehensive "physics of failure" study. The paper itself is well done; in particular there are no pointless mathematical expressions scattered throughout to give the appearance of some sort of sophistication.

85 DEMONSTRATION/MEASUREMENT

R68-14034 ASQC 850; 433; 824

BAYESIAN RELIABILITY DEMONSTRATION PLANS.

Austin J. Bonis (Bell Aerosystems Co., Buffalo, N. Y.).

In: Transactions of 1967 Spring Product Assurance Conference and Technical Exhibit, Long Island, N. Y., Apr. 15, 1967 Conference sponsored by the American Society for Quality Control, the Standards Engineers Society and the Society of American Value Engineers. Arno Press, Inc., [1967], p. 121–133. 15 refs.

Difficulties encountered in present-day reliability determinations are mentioned, and a Bayesian reliability demonstration test is presented as a practical means of overcoming these difficulties. This test method permits the mathematical combination of engineering judgments and experience with limited test data; and seven examples are included to illustrate the use of the proposed method. The exponential distribution for the usual case of electronic equipment is discussed, and range and estimation of reliability parameters are considered. Tables indicate the maximum allowable number of failures under three different conditions. M.W.R.

Review: This paper is the same as the one covered by R67-12972.

R68-14035 ASQC 850

AN INTEGRATED PLAN FOR RELIABILITY DEMONSTRATION THROUGH SAFETY MARGIN TESTING.

Robert J. Schulhof and I. Paul Sternberg (Hughes Aircraft Co., Aerospace Group, Space Systems Div., El Segundo, Calif.).

(American Society for Quality Control, Annual Technical Conference, 20th, New York, June 1–3, 1966.) In: Transactions of 1967 Spring Product Assurance Conference and Technical Exhibit, Long Island, N. Y., Apr. 15, 1967 Conference sponsored by the American Society for Quality Control, the Standards Engineers Society, and the Society of American Value Engineers. Arno Press, Inc., [1967], p. 135–141. 5 refs.

(A67-17253)

Examination of the methods by which development and qualification testing can be planned to satisfy design evaluation and verification and to make possible the measurement of reliability. It is noted that the plan is practical, accomplishes its dual purpose, and is responsive to economic constraints. The universe of test situations divides basically into two categories—one where true strength may be determined and another where a one-shot device is to be tested. An example of each category is considered. IAA

Review: This paper is the same as the one covered by R66-12782.

R68-14048 ASQC 851

THE APPLICATION OF OVERSTRESS TESTING-TO-FAILURE TO AIRBORNE ELECTRONICS—A STATUS REPORT.

J. J. Bussolini (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).

In: Institute of Electrical and Electronics Engineers International Convention, New York, March 20–23, 1967, 1967 IEEE International Convention Record, vol. 15, part 14—Reliability; Industrial Electronics. New York, IEEE, Inc., 1967, p. 3–8.

(A68-11667)

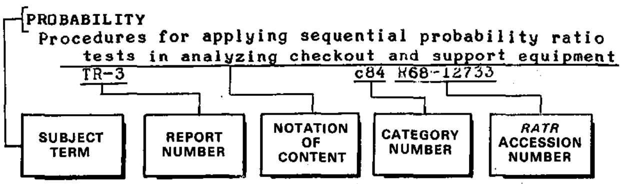
Discussion of the results of three specific applications of environmental overstress testing-to-failure techniques to equipment from airborne radar, display, and computer electronic systems. Comparisons of laboratory and flight test data are presented to illustrate the validity of the test technique for design analysis. Multiple-source supply evaluation is discussed, and a case history is cited. Of possible future significance is the presentation of measured and projected stress-time relationships which equate environmental safety margins to estimated and measured mean time between failure. IAA

Review: This paper is the same as the one covered by R68-13920.

SUBJECT INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 10

Typical Subject Index Listing



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B

C

D

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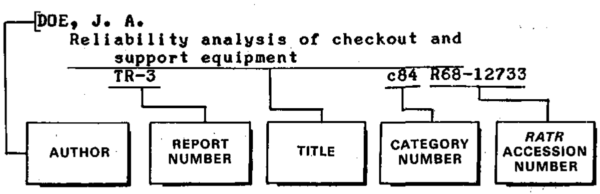
PERSONAL AUTHOR INDEX

Typical Personal Author Index Listing



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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 10

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Reliability Abstracts and Technical Reviews

NOVEMBER 1968

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Number 11

R68-14077—R68-14125

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R68-12733 ASQC 844; 413
General Equipment Company, Banville, Calif.
RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
John A. Doe 23 Sep. 1966 27 p refs
(Contract NAS15-13411)
(TR-3; AD-629305; N68-15098) CFSTI: HC $3.00/MF $0.65

***RATR* ACCESSION NUMBER** · **TITLE** · **JOURNAL REFERENCE** · **ASQC CODE** · **AUTHOR AND AFFILIATION** · ***IAA* ACCESSION NUMBER**

R68-12739 ASQC 814
SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.)
Electric Journal, vol. 8, Apr. 1966, p 478–492.
(A68-12569)

***RATR* ACCESSION NUMBER** · **TITLE** · **CONFERENCE OR SYMPOSIUM REFERENCE** · ***IAA* ACCESSION NUMBER** · **ASQC CODES** · **AUTHORS AND AFFILIATIONS** · **AVAILABILITY AND PRICE**

R68-12765 ASQC 773; 221; 823
TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.)
Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13–17, 1966, 8 p
Available from Assoc. of Reliability Eng., New York: $1.00
(A68-12407)

VOLUME 8 NUMBER 11

Reliability Abstracts and Technical Reviews

A Monthly Publication

of the National Aeronautics and Space Administration

November 1968

80 RELIABILITY

R68-14084 ASQC 802
RELIABILITY PRINCIPLES AND PRACTICES.
S. R. Calabro (International Electric Corp., Product Assurance Div., Paramus, N. J.).
New York, McGraw-Hill Book Co., Inc., 1962, 371 p. 60 refs.

Fundamental concepts underlying modern reliability theory are presented, along with their application to the solution of practical problems. A general survey of the reliability field is included, and comparisons are drawn with quality control concepts. Probability theory and statistical distributions are considered in terms of measures of central tendency and dispersion; series and parallel redundancy; normal, binomial, and Poisson distributions; and the exponential failure law. Purposes, sources, analysis, and evaluation of reliability data are covered; and use of the chi square and approximation methods are described. Maintainability and availability of equipment and mission are treated; and various sampling methods are presented. Reliability and availability prediction methods, principles of reliability design, and reliability specifications are also covered in this textbook which also mentions United States governmental requirements and inspection procedures. Product assurance operations and management of the reliability program are reviewed, and typical product assurance organizational structures are included.
M.W.R.

Review: This was one of the first books on Reliability to be published and since its publication many more have followed in its footsteps with varying degrees of success and coverage. It is reasonable to consider the book from the present standpoint some six years after it was published and four years after it was selected for an Engineer's Book Club. The book is as good as it ever was for learning about reliability. The statistical aspects of the book are the weakest, and a reliability engineer should not learn his statistics from it. The concepts of Maintainability and Availability and how-to-design-for-reliability are good. Obviously the author made some choices in what he would emphasize, and it is difficult to fault his choices in this regard. There are formulas available in the text which may not be readily available elsewhere and thus if one is building a library of reliability books this one can find a place in it. One should hesitate to purchase it as his only reliability book. Very few parts of the book are out of date, and the few that are (largely dealing with Government documents) are easily recognized. Unfortunately, the main complaints about the book have nothing to do with the date of publication. Since a reader ordinarily presumes a book is good unless it is otherwise pointed out to him, the following specific chapter-by-chapter comments are largely fault-finding ones. In fairness to the author, it should be pointed out that (a) some of the "faults" are, rather, limitations which he may have intended since he was trying to avoid abstract statistical and mathematical techniques and (b) some of the items which are herein considered faults are, by some, considered virtues. Unfortunately, the inexperienced reader has no good basis for passing judgment on either the book or its reviews. *Chapter 1.* In general this chapter is about half out of date and half current. (a) The author tries to distinguish between quality and reliability, but both fields are growing, expanding, and otherwise changing so that the distinctions are at best a matter of controversy. (b) In discussing the methods of achieving reliability, the grass appears to be greener on the other side of the fence; Architects and civil engineers are construed to have negligible problems with reliability in contrast to those in electronics. Even if it were true at the time, it is certainly no longer so with exotic materials and their unknown properties pressing hard from one direction, and with costs and other engineering parameters pressing hard from other directions. But it does indicate that we may expect some limitation in the book to the field of electronics and electrical engineering. (c) The use of screening is generally deprecated although it has come to be considered highly useful for semiconductors. (d) It is not clear from the discussion on reliability specifications whether a calculated value of reliability (as opposed to actual test results on the items) is acceptable as demonstrating reliability. There is controversy on this item now as there has been and the issue is usually resolved by other considerations, namely the availability of time and money. *Chapter 2.* Obviously the definitions of statistical terms have not changed, but the author's assertions about what is best may have changed, depending on the facilities for calculation. Some of the details about calculating means and standard deviations along with why certain formulas should or should not be used depend on the means available for actually doing the calculations. For example, whether one is doing it by hand, by mechanical desk calculator, or by a programmed electronic computer will make a difference in the method used. If electronic computers are used rounding errors may be much more significant in one method than in another and for this reason either competent advice should be obtained beforehand or one should study the situation carefully. *Chapter 3.* There are distinct limitations in the presentation in this chapter. (a) When the author says theoretically something is so, the novice must be careful to interpret this remark properly. What the phrase generally means (here and elsewhere) is "...according to the simple-minded model being used at present it is so..." (b) The author has chosen not to use a mathematical basis for probability, but rather to define it in terms of relative frequency. Which method to use is still a matter of some controversy in engineering, but the trend seems to be toward the approach used, for example, in the recent book "Probabilistic Reliability: An Engineering Approach," by Martin L. Shooman, McGraw-Hill, Inc., 1968, which is the mathematical model approach. The latter can be defended from both the high-powered theoretical and the practical engineering points of view. Thus the author's approach, while not incorrect, is not as useful as another one would have been. (c) As is common in this kind of text, the author uses the word "independent" when referring to events or random variables. However, when writing for engineers,

who are not statisticians, it is wise to use the complete phrase "statistical independence", so that they will realize the word is being used in a particular technical sense rather than in the cause–effect lay sense they would otherwise infer. (d) A similar comment can be made about the giving of a statistic which is calculated from sample data. For engineers, it is wise to state, for example, that it is a *sample* average or the *sample* reliability when that is meant, or conversely to state that it is the *estimated population* reliability if that is meant. Otherwise, the uninitiated (and sometimes even the experts) have to look back to find out which one was meant and if the author was correct. (e) Another distinct disadvantage is that in every case (except when discussing the addition law) the events are considered to be statistically independent. Conditional probabilities are not even mentioned. It would be very easy for the novice (and this chapter is designed for him) not to realize that statistically dependent events exist. *Chapter 4.* (a) The "constant cause chance system" is a device which ineffectually relates a mathematical model to the physical world. This is a subject of some misunderstanding among engineers. Suffice it to say here that in engineering problems it is virtually always a matter of resources as to whether causes are assignable or not and that the use of a statistical distribution has nothing to do with cause–effect since we are presuming at this level that cause and effect are always in operation. (The Heisenberg uncertainty principle is completely negligible in all of these cases.) (b) The author is incorrect in stating that the use of a biased coin would not result in a Normal distribution in his experiments. He does not point out that in his coin-tossing experiment, where the answers are discrete numbers, representation of the answers by a continuous distribution leads to difficulties. He implies that the three sigma limits of the Normal curve are the extreme values of the curve, which, of course, is not correct. He also says that only for the Normal distribution is the standard deviation approximately 1/6 of the range. Since the range (or more properly, the domain) of the variable is from $+\infty$ to $-\infty$, this statement is obviously in error. It is worth noting that in some countries $\pm 4\sigma$ is used rather than $\pm 3\sigma$ which is popular in this country. (c) Some of the discussion (e.g., on p. 45) is specific to the Normal distribution but is stated in such a way as to imply more general applicability. (d) The author, in trying to be practical, can easily confuse the reader between the theoretical model, which he has not sufficiently described, and what the author considers to be practical. (e) In Section 4.4, the author implies that the area under a Normal distribution is not unity unless the standard deviation is one and its mean zero. But the area under *any* probability density function is unity. In general, this chapter gives some of the properties of Normal distributions, but it is a poor place to learn about them because of the gross intermixing of the theoretical and the "practical". *Chapter 5.* Nowhere in this chapter is the actual binomial distribution given. The author says that "...there is a simple method for expanding the binomial which is based on certain rules of thumb." These are not rules of thumb but are exact formulas (identities). The customary formulas for the binomial coefficients are not given; one has to infer them from some special cases. There is a misprint in Equation 5.3: the subscript n-1 should be n-i. *Chapter 6.* This chapter is subject to some of the same criticisms as were made above regarding the earlier chapters. The following additional comments are applicable. (a) The author's definition of failure and hazard rates is always over a finite time interval; the concept of instantaneous rate is not used. (b) The term "ratio part failure rate" is no longer in use. It is now most often referred to as the failure rate whereas the author's failure rate is called the hazard rate (or failure rate when the reliability is high enough that the two are indistinguishable). (c) The assertion that "...the parts which comprise an electronic computer usually operate in the wearout phase..." is no longer considered to be true if, in fact, it was true at the time. Semiconductors presumably do not have a period of sharply increasing hazard rate in any conceivable life of a computer. (d) In discussing the product rule for the series system, the author ignores the restriction to failure events which are statistically independent. (e) The discussion of combined populations in Sec 6.11 is not clear. In summary, Chapters 2–6 which are the mathematical presentation are not a strong part of the book, and the difficulties do not lie with when the text was written. *Chapter 7.* A large part of this chapter can be considered dated. However, methods of gathering reliability data are still inadequate. (a) No mention is made of the IDEP (which was known four years before the text was published), and the historical part is rather incomplete in that some of the pioneering publications of RCA and RADC are not mentioned. (b) "Inherent reliability" is a poor term to use since it does not have a meaningful definition. One of the best definitions of inherent reliability is "that reliability which a designer would predict if he could disallow any failures he thought were not his own fault". Thus, an imaginative aggressive self-confident designer can achieve very high inherent reliabilities. (c) Catastrophic failures are called chance failures apparently in distinction to degradation failures; obviously both can use stochastic descriptions for their behavior. (d) The author's use of the term independent failure is not clear. *Chapter 8.* This chapter contains a few deficiencies, none of which are related to the time of writing. It can be used for calculations as shown by the author. (a) The author does not distinguish between mean time between failure or mean life; the book by Shooman mentioned above makes this appropriate distinction. (b) The author has considered no failure distribution other than the exponential. This, of course, is very misleading, since various other distributions can be used. (c) The author discusses the term confidence without distinguishing between statistical confidence and engineering confidence. (d) The discussion on the distribution of variance applies to Normal distributions, and the statistic under consideration is S^2, not the variance of the sample. It is not clear, when α and β are used in this same formula, how they should be chosen; it turns out from the example one can assume that α and β are the same (in which case why not write them the same?). *Chapter 9.* This chapter on Maintainability and Availability received a great deal of popular acclaim when the book was published. The material is less new now and much more accepted—probably due in large part to this particular book. (a) The author makes the blithe assumption that maintainability is always given by the exponential distribution which limits this discussion. (b) The reader, even in this chapter, will want to devise his own methods for sorting out the essential and good parts of the author's message and those which are better ignored. An example of this latter type is "The purpose of the scheduled maintenance is to cull and eliminate the wearout failures. It has no effect on catastrophic failures, which are due purely to chance." The first sentence is true, the second one is meaningless. (c) There are a great many formulas in Chapter 9 concerning availability and maintainability; most of these were not checked. The main caution the reader should observe is to be sure that the assumptions under which they were derived are reasonable for his case. Unfortunately, these assumptions are not always readily ascertainable. *Chapter 10.* There is little in the chapter to out-date the material. (a) The attempt to introduce a "failure bit" as 10^{-8} failures/hour has not taken hold in the reliability literature, probably because of the confusion with the term bit as used in information theory. (b) When the author refers to MIL-STD-105A the reader should interpret this as meaning the latest version of MIL-STD-105, which at the time the book was written was C, not A. (c) Sampling plans other than those cited are possible, and one should not rely on this chapter alone for his knowledge of sampling plans. (d) A difficulty not mentioned in this chapter is that if the reliability is very high then the producer is at a serious disadvantage in trying to use this kind of test. Unless his equipment hazard rate is much lower than the specification, he cannot reasonably hope to pass an economically-feasible test. (e) The disadvantage of this chapter is not that any of the material is dated as such, but it has a very narrow scope which implies that these are the only tests that one runs, whereas such is not the case. (f) It is worthwhile pointing out that these tests mentioned by the author do not necessarily presume the exponential distribution. For a given time period any reliability function can be written as $\exp(-\bar{h}t)$ where $\bar{h}$

is the mean hazard rate over the time interval t. *Chapter 11*. This chapter was not checked in great detail since it is presumed that it repeats reasonably well-known sampling and control charting procedures which have been adapted to reliability. (a) The author's claim that a constant hazard rate is a necessary condition for mature design should be taken as the author's definition of "mature design" and "mature design" should be interpreted here in no other way—otherwise the statement gets one into trouble. (b) Whenever one cumulates the results from subsamples for a large sample, a statistician should be consulted about the correct procedure used to analyze the data, since the results at one stage may depend on the data for preceding stages. (c) The author's K^2 function has not achieved prominent use in the reliability literature, for for some sampling plans it may well be a distinct convenience. (d) In recent years much work has been done, especially by Aroian, on truncated sequential sampling plans, which removes some of the difficulties associated by the author with sequential sampling. (e) Little or no use is made of reliability growth curves; some of the wording can be interpreted as deprecating them, since the book says that sampling plans should be used only for "mature" designs. *Chapter 12*. (a) One must be careful about the phrase: one cannot test/inspect reliability or quality into a device. In one sense, of course, this is true, especially for devices which cannot be subdivided. But one can certainly inspect and test *un*reliability and *poor* quality *out* of a large piece of equipment or system. This is one of the major reasons for a countdown, for example. (b) The author seems to feel that if a constant hazard rate does not apply that reliability predictions cannot be made. This is not accurate. (c) He also says that statistical independence of failures implies the Poisson/exponential distribution. This is not true—they have nothing necessarily to do with each other. (d) Even though the author has cautioned against excessive reliance on reliability calculations, in his example 12-2 he estimates the hazard rate of a receiver to five significant figures; two significant figures would have been more than adequate to express the actual accuracy. (e) The only concern is with statistically independent failures. The problems associated with drift failures and the interactions due to drift of several components are not considered at all. (f) An engineer should not take the book's word for the fact that one approach is better than another, since the various trade-offs involved are rarely explicitly given. *Chapter 13*. A good many practical considerations in design are given in this chapter. They are not out-dated and they probably never will be, since it is likely that designers will be making the same mistakes 30–40 years from now that they make today (many of them are *now* making mistakes that were made 30–40 years ago). (a) The emphasis on human engineering aspects of reliable design is very good. (b) One thing not mentioned that is difficult for a designer to handle is the case where the mission and intended environment of the equipment are very strictly defined/yet in actual practice the designer is quite sure that the actual mission and actual use environment will be appreciably different. This can often be the case for example, with weapons that are used by the infantry. (c) A conspicuous omission is the Design Review which has proved its worth through the years and is considered by many to be an essential part of high-reliability design. (d) The methods of apportioning reliability to subsystems are not dealt with in any detail. (e) The PSMR-1 (Darnell) report is not mentioned in the main text. *Chapter 14*. There is still some controversy about the best way to handle reliability specifications. The author's opinions on this are still somewhat in vogue, and the relative position has probably not changed appreciably since it was written. For example, there are those who advocate a good qualitative statement of the objectives even though they may use what the author terms "meaningless adjectives". Many reliability specifications today provide for proof only in the form of a calculation from the drawings, not from life tests of the actual equipment. The listing of Government and associated documents concerning reliability requirements has changed appreciably in the intervening years, and more up-to-date lists should be consulted (even though not discussed in the text, the PSMR-1 report is listed). The author's hopes for simplification and straightening out of many of these documents have been only partially realized. Even though the situation might be better now, there are those who feel that that is not saying much. Chapter 14 is one of the more dated chapters; in fact it was not completely up-to-date when it was written. *Chapter 15* is more for interest in background and direction, and is still reasonably applicable. *Chapter 16*—on the management of the reliability program—presents the author's preference. In the absence of any other information it is a good place to start. Numerous articles have appeared on this topic before and since. Those who find themselves in the unenviable position of overhauling or constructing such a department from scratch should consult the relevant literature. A good source of papers on this is the Proceedings of the Annual Symposia on Reliability. The major difficulty that one should be aware of in reading papers on how management systems work or should work is that the papers are usually designed to cast the best light on the way the author's company is organized, and rarely do they deal with what happens when things go wrong, when schedules are slipping, and pressure from top management is strong. Also, requirements which start out with picking only excellent people to work in a particular department should be viewed with great caution. Since almost any organization, however complex, can work with excellent people, the real test of an organizational system is how it works when an average group of engineers with average managers are employed. This chapter contains many good comments, and if they are interpreted as comments rather than as ultimate truths, any reader can still get much valuable information from it. In connection with the definitions of terms in Appendix 1, it should be noted that some of these are for the way in which the author has used the term in the book as opposed to a generally accepted definition. (Many of the terms do not have generally accepted definitions.) The Appendices were not reviewed in detail. Some of the excerpts from Government documents are undoubtedly out of date, and the reader should look for more up-to-date information.

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-14098 ASQC 810

Lockheed-Georgia Co., Marietta.

RELIABILITY PREDICTIONS FROM AN ART TO A SCIENCE

K. S. Wilson 7 Nov. 1967 9 p Presented at FAA Symp., Oklahoma City, 7–9 Nov. 1967

(AD-664372; N68-18691)

The paper comments upon reliability predictions and the degree to which precise methods are being employed to make quantitative estimates of future reliability performance. The demand for high product reliability and maintainability is forcing attention to these subjects from the large system manufacturer down to the piece-part producer. Contracting for guaranteed reliability performance involves heavy risks, and accurate predictions are needed early in the program. The state-of-the-art in making precise quantitative reliability estimates in the airplane business is considered primitive and largely a matter of exercising judgment in combining bits of historical data and wishful thinking. A large portion of the aerospace industry is participating, and slow progress is being made toward the development of a worth-while and effective capability. Author (TAB)

Review: This paper is a commentary on the problems encountered by the hardware producer who contracts for guaranteed

reliability performance. While the specific reference is to the aircraft manufacturer, the problems are the same for other producers of military and aerospace equipment. The author's main contention is that reliability predictions are far from being on a scientific basis, which is the thought expressed in the title of the paper. He makes some suggestions for improving the situation, which include concentration of effort where it will do the most good, systematic effort in the physics of failure, more widespread understanding of analytical techniques and statistical methods, and the provision of adequate and compatible data systems. These are good suggestions. However, there is growing doubt that reliability physics will ever perform the magic predicted some years ago by its more enthusiastic proponents. The need for adequate reliability data is serious, and has been mentioned frequently in the literature. The paper will be worthwhile reading for managers and others in a position to implement at least some of the suggestions which are made.

R68-14108 ASQC 810; 830

CAN WE AFFORD DESIGN ASSURANCE?

R. P. Berkowitz (Honeywell, Inc., Computer Control Div., Products Assurance Dept., Minneapolis, Minn.).

Computer Design, no. 6, June 1968, p. 34, 36, 37.

Development of design assurance functions for commercial digital computers is discussed in terms of the increasing use of automated equipment and the costs of corrective actions because of faulty design. Computer design must be reviewed in light of effects from potential hazards; and each safeguard should be reviewed in relation to product specifications and intended applications. General comments are offered on the following areas of concern in design assurance: electromagnetic interference, intrinsic safety, environmental capability, maintainability criteria, parts qualification, and standards. M.W.R.

Review: The author, of course, answers his own question in the affirmative and goes on to list several categories wherein the design should be checked. The points are well taken and are made at a qualitative managerial level as opposed to a detailed technical level. The author brings in the economics of the situation and points out that there is usually a maximum amount of product goodness for which one wants to pay. The term "intrinsic safety" is apparently not used in a technical sense that is coming into vogue but in the general sense of safety of the equipment. The paper has little for experienced reliability engineers.

R68-14117 ASQC 810; 767

APPLICATION OF RELIABILITY THEORY TO CALIBRATION INTERVALS.

C. W. Gebhardt (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Measurement Standards Laboratory, Sunnyvale, Calif.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6-8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 233-242. 6 refs.

(A68-31422)

Description of the application of reliability and statistical theory to the adjustment of calibration intervals (the recall period). The exponential failure distribution in the interpretation of instrument performance data is based on the following criteria: (1) the laboratory adheres to stringent testing procedures, and (2) scheduled and nonscheduled preventive maintenance programs are in full effect. Using instrument performance data from a given recall period, the exponential failure distribution is used to estimate instrument reliability at some other interval. Confidence limits are then applied to this estimate to determine that instrument reliability goals will be met at the new recall period. The end result is a simple chart which utilizes raw instrument performance data to arrive at the answers to the questions of whether the data are of sufficient quality and quantity to consider a change in recall period and, if so, what change is warranted by the data. IAA

Review: The reliability theory referred to in the title of this paper is that pertaining to the exponential distribution of times to failure. It is used to estimate instrument reliability, where a failure is interpreted as an out-of-tolerance condition of the instrument. The author's justification for the use of the exponential formula is that the failures are of a "chance" or random variety. This is a misconception which occurs quite frequently in the reliability literature. Randomness per se does not justify the use of the exponential distribution any more than any other distribution of a random variable such as, e.g., the Normal distribution. In fact, if a wearout characteristic is operating in the case of the out-of-tolerance conditions or failures of the instruments, it would be more reasonable to base the analysis on the Normal distribution. The lack of justification for the use of the exponential distribution constitutes a major weakness of the paper. Apart from this, it will serve as an illustration of an approach to the problem of optimizing calibration intervals. As such, it will be of more value to managers concerned with this function than to those who analyze the data.

R68-14118 ASQC 817; 353; 833; 844; 851

SCREENING OPTIMIZATION.

Chris Biagini and Ben. F. Clemons (General Dynamics Corp., Electronics Div., Rochester, N. Y.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6-8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 325-333. 1 ref.

(A68-31425)

Discussion of one approach to optimization of screening programs. The program is optimized with respect to cost by applying the basic mathematical techniques. In its most general form the method considers direct screening costs, test costs, penalties and incentives, and rework costs. The next logical step in evolution of this technique would be expansion to cover the effects of screening on field usage costs, in effect, making it a factor of life-cycle costs. Practical problems associated with the implementation of this technique are discussed, and guidelines are presented to suggest reasonable solutions. IAA

Review: The authors have attacked a most difficult subject and have done the job well. As a first paper on a controversial subject it would be easy to criticize if the reviewer did not agree; on the other hand a sympathetic reviewer has an equally difficult time in that he would like to expand and improve the authors' start. The authors have found that the economic justification for the cost of doing all the preventive reliability steps usually prescribed by prudent program management is difficult to prepare, and have as a result resorted to a cost analysis combined with a reliability study to find an optimum solution. It is hoped that others in the field of reliability/quality control and management of programs for high-reliability product take up where these authors stopped and develop additional tools for cost/test justification analysis. Additional cost elements which should be included in future work are delivery schedule delays, facilities, storage and trouble-shooting labor, and the possibility that test costs will increase when screening methods are not used. In reporting the findings of an analysis of this type to management it might prove useful to use graphical displays rather than a printout from a computer; the relationships will be more readily visible without a great deal of reading and/or study. These authors are to be congratulated for their foresight and originality.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-14077 ASQC 821
Rand Corp., Santa Monica, Calif.
ALLOCATING UNRELIABLE UNITS TO RANDOM DEMANDS
Allen Klinger and Thomas A. Brown Nov. 1967 64 p refs
(Contract F44620-67-C-0015)
(RM-5302-PR; AD-661540; N68-33275)

The results presented were obtained in a systems analysis study. Analytical expressions are presented for such quantities as the probability of successfully supplying a random number of demands (or customers) with successfully functioning units drawn from a fixed supply of items which fail at random. The mathematical properties of the several functions considered useful are investigated in some detail. Author (TAB)

Review: This is a quite detailed mathematical presentation addressed to the problem of allocating a fixed inventory of unreliable units to a random number of demands. That is to say, randomness is present in the number of demands and also in the failures of the units in the inventory. The paper will be of interest to theorists concerned with the quantitative analysis of complex systems, in particular those involving stochastic allocation situations. A companion document, RM-5484-PR, December, 1967 (AD663379) presents the optimum return functions and allocation strategies of this report in a graphical form. These facilitate comparisons between the different optimization models and display the dependence of these functions on the various parameters involved.

R68-14080 ASQC 824
Ford Motor Co., Dearborn, Mich.
REVISED TABLES FOR ASYMPTOTIC EFFICIENCIES OF THE MOMENT ESTIMATORS FOR THE PARAMETERS OF THE WEIBULL LAWS
Satya D. Dubey Repr. from *Naval Res. Logistics Quarterly*, v. 14, no. 2, Jun. 1967 p 261–267 refs
(NAVSO-P-1278; AD-655602; N68-88001)

Revised tables are presented for determining the asymptotic efficiencies of moment estimators for Weibull parameters. Chebyshev polynomials were used in the computations; and both joint and individual efficiencies are tabulated. M.W.R.

Review: This paper presents revised tables to accompany the paper covered by R67-13208. They provide greater accuracy in the tabulated values of the asymptotic efficiencies of the moment estimators of Weibull parameters. These results will be of interest to the theorist rather than to the reliability analyst, since they pertain to a rather sophisticated mathematical consideration, and large-sample results are not of great practical importance in Reliability.

R68-14082 ASQC 824
PREDICTION OF PER CENT FAILURE FROM STRESS/STRENGTH INTERFERENCE.
Charles Lipson and Narendra J. Sheth (Michigan University, Dept. of Mechanical Engineering, Ann Arbor, Mich.).
Society of Automotive Engineers, Automotive Engineering Congress, Detroit, Mich., Jan. 8–12, 1968, Paper. 19 p. 32 refs.
(SAE Paper 680084; A68-17319) Members, $0.75; nonmembers, $1.00

Discussion of the development of a practical engineering tool to be used in predicting the percent failures of mechanical components. In order to predict the percent failures, it is necessary to convert life data of conventional S-N diagrams into strength data. The distribution function of these strength data is then determined. It was found that the three-parameter Weibull distribution fits these data best. After finding the distribution function (Weibull) and its parameters for strength, the problem of distribution of stress is considered. On the basis of past experiences, the stress distribution is assumed to be normal. After values of the parameters of these interfering distributions of stress and strength have been determined, probabilities of failure of parts are calculated. An example is solved to demonstrate the application of the interference technique developed to predict percent failures. Author (IAA)

Review: Practical interpretation, approximation formulas, and applications data concerning the conventional stress-strength problem are emphasized in this paper. The material is essentially extracted from the report that was prepared by the authors and is cited as Reference 2 in the paper (and covered by R66-12503). The data tabulations which are presented are mainly strength data for certain materials and it is pointed out that the area of stress distributions needs further study. The underlying stress-strength model is not defined in the paper, but it can be found in Reference 2 or in some of the standard reliability books. A note of caution for stress-strength problems where the same stress is applied to multiple items or materials is that the failures will not be statistically independent. The item covered by R68-13868 provides further elaboration on this point. In Fig. 1 showing both the stress and strength distributions, the authors refer to the shaded area as a "measure of interference." This is not correct. It is the abscissa segment between the points where two distributions actually touch the abscissa that is related to the interference (and that only gives the stress-strength region over which failure is possible). To shade the overlap area is to mislead many people. The authors show tables of the median plotting position. There are many favored plotting positions, and rarely is the exact method important. For those who occasionally make these plots, the average (expected) plotting position is easier to remember and needs no tables ($p = i/(n+1)$ for the i-th failure out of n specimens). While the use of a three-parameter Wiebull distribution may be justified under conditions where there is extensive current data on the material and its processing, the more tractable Normal or logNormal distributions are adequate in the more usual situation where an engineer has virtually no distributional information. The mathematics need be no more complicated than required by the uncertainty of the assumptions.

R68-14083 ASQC 824
SOME SIMPLE ESTIMATORS FOR THE SHAPE PARAMETER OF THE WEIBULL LAWS.
Satya D. Dubey (Ford Motor Co., Dearborn, Mich.).
Naval Research Logistics Quarterly, vol. 14, Dec. 1967, p. 489–512. 7 refs.
(A68-17035)

Description of simple tabular methods for estimating the shape parameter of the Weibull distribution. These estimates of the shape parameter are used to obtain simple estimates of the other parameters of the Weibull distribution. In many practical situations, these simple estimates of the parameters can be considered satisfactory, particularly when the sample size is large; nevertheless, they can be used as initial values toward the solution of the likelihood equations for computing the maximum likelihood estimators of these parameters. A numerical example is used to illustrate various simple tabular methods of estimating the shape parameter. IAA

Review: This paper makes a worthwhile contribution to the methodology related to the Weibull distribution. It enables

the estimation of the shape parameter from functions of the sample moments. This is accomplished through the tabulation of quantities called standardized measures which are ratios of moments of the distribution and are also functions of the shape parameter only. Their use in obtaining estimates of the shape parameter is illustrated in the paper. One calculates the necessary functions of the sample moments and refers to the table for the estimate of the shape parameter. Tables for estimating the shape parameter on the basis of sample percentiles are also given. The estimates dealt with in this paper are relatively easy to obtain compared to the maximum likelihood estimators which require the solution of relatively complex equations. For large samples the estimates obtained by the methods of this paper will generally be satisfactory. However, as the author has pointed out, they may be used to obtain initial values for use in the iterative solutions of the maximum likelihood equations. This author has made extensive contributions to the theory and methodology related to the Weibull distribution, and some four of his earlier papers are referenced in this one.

R68-14093 ASQC 824
Naval Civil Engineering Lab., Port Hueneme, Calif.
EFFICIENCY OF TWO ESTIMATORS FOR A POISSON DISTRIBUTION
W. L. Wilcoxson and M. L. Eaton Apr. 1967 20 p refs
(TR-519; AD-649910; N67-29667) CFSTI: HC $3.00/MF $0.65

A given Poisson phenomenon is characterized by a single parameter. From observed records this parameter may be estimated in at least two ways, namely by the mean and variance estimates from the sample, each computed from the observations. The efficiency of the variance estimate (as compared with the mean estimate) decays rapidly as the value of the parameter increases, and increases slowly with increasing sample sizes. TAB

Review: This report is addressed to an interesting problem in the theory of estimation, namely, a comparison of the sample mean and the sample variance as estimators of the single parameter of a Poisson distribution. It has pertinence to Reliability since numbers of failures or frequency of defective items frequently follow a Poisson distribution. The results indicate that the efficiency of the variance estimate relative to the mean estimate drops as the parameter value increases, and tends to increase slowly with sample size. From the standpoint of ease of calculation, one would naturally prefer the mean to the variance. However, the authors mention an illustration in which the variance estimate is all that is available. It is a situation involving nuclear transformations in which corrections are made for mechanical counting errors and sampling errors. Without the motivation of this practical problem, the paper would be a purely mathematical exercise.

R68-14096 ASQC 824; 822; 838
EXACT MOMENTS OF THE ORDER STATISTICS OF THE GEOMETRIC DISTRIBUTION AND THEIR RELATION TO INVERSE SAMPLING AND RELIABILITY OF REDUNDANT SYSTEMS.
Barry H. Margolin and Herbert S. Winokur, Jr. (Harvard Univ., Cambridge, Mass.).
Journal of the American Statistical Association, no. 319, Sep. 1967, p. 915–925. 10 refs.

Formulas for the first two moments of the order statistics from a geometric distribution are presented in closed form. Brief illustrative tables of these statistics from a geometric distribution are included, and two related dice games are discussed. The distribution of the range of a set of independent observations from a geometric distribution is presented in closed form. A system of redundant components which performs a given task repetitively at discrete times and its statistical equivalent, an inverse sampling scheme, are studied. The distribution of the number of stages until the scheme terminates or the system fails is shown to be identical to the distribution of a specific order statistic from a geometric distribution. A Markov chain formulation is presented which facilitates certain system reliability and cost analyses. Author

Review: This is a mathematical paper concerned with the moments named in the title, and attention is given to the orientation of the work relative to other published results. In particular, reference is made to the paper by Weiss which was covered by R62-10258. That paper was concerned with the operation of systems of N redundant and failure-independent elements which perform a given task repetitively at stages or discrete intervals of time, where each component of the system has a constant probability of failure at each stage. It is shown in the present paper that the system studied by Weiss is equivalent to an inverse sampling scheme which can be formulated as a Markov chain, and an example is given to show how the Markov chain formulation may be used to assess the probability that a particular type of redundant system will function properly. These results are not of the type which can be of practical use to the analyst or the engineer; rather, they will be of interest to those who are concerned with advancing reliability theory.

R68-14099 ASQC 824; 822
Rocketdyne, Canoga Park, Calif.
RESULTS ON LOCATION AND SCALE PARAMETER ESTIMATION WITH APPLICATION TO THE EXTREME-VALUE DISTRIBUTION
Nancy R. Mann Wright-Patterson AFB, Ohio ARL Feb. 1967 187 p refs
(Contract AF 33(615)-2818)
(ARL-67-0023; AD-653575; N67-34956) CFSTI: HC $3.00/MF $0.65

The report gives results concerning estimation of location and scale parameters. Most of the work pertains to the first extreme-value distribution of smallest values, the distribution of the natural logarithms of failure times having the two-parameter Weibull distribution. Experimental designs are derived, under the assumption that log failure times are polynomial functions of the reciprocal of stress level and have the extreme-value distribution, for over-stress life tests. These designs yield least-squares curves with minimum variance at a specified (nominal) stress level below the levels at which the life test is conducted. An estimate of the extreme-value location parameter u associated with the nominal stress level and the relationship between u and stress level can be obtained from the least squares curve. Other extreme-value results apply to a life test conducted at a single fixed stress level. Author (TAB)

Review: This report, including its appendices, constitutes an extensive mathematical treatment of the topic indicated in the title. The relevance of much of it to reliability analysis arises as a result of the fairly common use of the Weibull distribution in reliability work. It will be useful to statisticians who are concerned with reliability analysis in which the Weibull distribution is involved, and with the design and analysis of over-stress life tests. The material is clearly written, presented in detail, and adequately referenced. However, it is not the sort of thing which the average engineer can pick up and use directly because considerable background and maturity in statistics is required in order to assimilate the material.

R68-14100 ASQC 824; 413; 553
Aerospace Research Labs., Wright-Patterson AFB, Ohio.
THEORY AND TABLES FOR TESTS OF HYPOTHESES CONCERNING THE MEAN AND THE VARIANCE OF A WEIBULL POPULATION Final Scientific Report
H. Leon Harter and Satya D. Dubey (Ford Motor Co.) Mar. 1967 401 p refs

(ARL-67-0059; AD-653593; N67-34089) CFSTI: HC $3.00/MF $0.65

A summary is given of the current state of knowledge concerning the analysis of data arising from Weibull populations. Five different parameterizations which have been used by various authors are given, and the relation of the various sets of parameters to each other and to the mean and the variance is explored. It is shown that the standardized cumulants are functions only of the shape parameter. An auxiliary table is given of the mean and the *variance of a Weibull population with location parameter 0 and* scale parameter 1 and of the standardized cumulants gamma sub k (k = 3,4,...,8), all for shape parameter m = 1.1(0.1)10.0. The theory is developed for tests of hypotheses concerning the mean and the variance of a Weibull population, based on the Weibull-Z, Weibull-T, and Weibull-V statistics, which are analogues of the normal-z, Student-t, and (chi square)/(degrees of freedom) statistics, respectively, the difference being that the underlying distribution is Weibull rather than normal. Percentage points of the Weibull-Z statistic are worked out by use of the Cornish–Fisher expansion technique and similar results for the Weibull-V and Weibull-T statistics are obtained by means of a Monte Carlo simulation. The percentage points are tabulated for all combinations of the above values of m; *sample sizes n = 2(1)40, 48, 60, 80, 120, 240,* infinity; and cumulative probabilities P = 0.0005, 0.01, 0.025, 0.05, 0.1, 0.25, 0.75, 0.9, 0.95, 0.975, 0.99, 0.995. Examples illustrating the use of the tables are given. Author (TAB)

Review: This report presents tests of hypotheses concerning the mean and the variance of a Weibull distribution, similar to the tests which are commonly available for the Normal distribution. The tables, which occupy the bulk of the report (366 pages), were obtained through the use of approximation theory and Monte Carlo simulation. The main text of the report consists of a discussion of the tests together with some background information on the state of knowledge of the Weibull distribution. An extensive list of references is given. The report will be of value to applied statisticians concerned with the analysis of Weibull data, which occur quite commonly in reliability and life testing.

R68-14103 ASQC 823

DETERMINING THE QUANTITATIVE INFLUENCE OF VARIOUS FACTORS ON THE INTENSITY OF FAILURE OF ELEMENTS OF AUTOMATIC SYSTEMS.

Ye. I. Vorob'yev and Yu. L. Solov'yev

Engineering Cybernetics, no. 4, 1967, p. 56–60. 2 refs.

A procedure is evolved for determining the quantitative influence of the various factors connected with climate and geography, operation, and maintenance on the failure of components in automated systems. The procedure separates the influence of the factors by representing failure rate as an elementary function with unknown coefficients. Information is obtained on number of component failures, duration of component use, and parameters influencing component reliability; and a table summarizes data on factors that cause the deviation of failure rates from nominal values. The procedure is considered less complex than existing methods for separating factors influencing failure rate. M.W.R.

Review: The problem of determining the separate influence of various factors on the reliability of the elements of a system is attacked in this paper. The approach involves representing the failure rate (intensity of failure in the author's terminology) by an elementary function with unknown coefficients. The set of elements in the system is then separated into subsets corresponding to the number of the unknown coefficients, leading to an equation for each subset. Provided that the system of equations is consistent and determinate, a solution for the unknown coefficients may be obtained. In principle this idea seems quite reasonable, and an example is given in the paper showing how it was used. This idea could have applicability in situations involving the determination of k factors to take into account the operation of components under various conditions. It would lend an element of sophistication to a procedure which is otherwise entirely empirical, but it would remain to be seen whether the practical results were really any better than those yielded by the purely empirical approach. The paper is really too brief to answer some of the questions which the reader may have. For example, is it assumed that the factors operate independently of one another? The first equation in the paper, which represents the failure intensity function for the system as a sum of functions with a term for each factor, seems to imply mutual independence of the factors, but this is not mentioned specifically. The separation of the influences of environmental, operating, and servicing conditions on the reliability of equipment is, as the author has pointed out, a complex practical problem. This paper contains the nucleus of an idea for an approach to its solution, which is worthy of attention by those who are concerned with this problem.

R68-14104 ASQC 824; 412

AN APPROACH TO THE STATISTICAL EVALUATION OF SYSTEM RELIABILITY.

V. A. Ivnitskiy.

(Akademiia Nauk SSSR, Izvestiia, Tekhnicheskaia Kibernetika, July–Aug. 1967, p. 50–57. 10 refs. In Russian.) *Engineering Cybernetics*, no. 4, 1967, p. 48–56. 10 refs.

(A68-41669)

Discussion of the *reliability function of a complex, highly* reliable electronic system. Confidence intervals for the system reliability are obtained from the test results of the system elements, with the aid of an expansion of the reliability function in a series in a small parameter representing the failure rate of the system components. An approach to the solution of the inverse problem (the determination of the system reliability from a given confidence interval) is also outlined. IAA

Review: The problem of determining confidence intervals for system reliability on the basis of data on components has received attention by statisticians interested in reliability estimation. Various approaches to the problem have been reported from time to time. The approach taken in this paper is that of using the Normal as an approximation to the distribution of the reliability estimate. The variance of the estimate is determined and the confidence intervals are then constructed. Unlike some translations from the Russian technical literature, this one is clearly presented and will be quite readable to those who have an appropriate background in mathematical statistics. Also considered is the problem of determining the number of tests on the components necessary for the construction of a given confidence interval. While addressed to important practical problems in reliability, this paper is a strictly mathematical approach, and consequently will be of interest to theorists who may glean some ideas from it or who may wish to compare it with some of the other proposed solutions to these problems.

R68-14110 ASQC 823

California Univ., Berkeley. Operations Research Center.

SELECTION PROCEDURES FOR RESTRICTED FAMILIES OF PROBABILITY DISTRIBUTIONS

Richard E. Barlow and Shanti S. Gupta (Purdue Univ.) Sep. 1967 38 p refs

(Contracts Nonr-3656(18); Nonr-1100(26))

(ORC-67-10; AD-664950; N68-19903)

The paper is primarily concerned with selecting a subset of k populations such that the probability is at least P star that the selected subset includes the population with the largest (smallest)

quantile of a given order alpha (0 < alpha < 1). In particular a procedure is proposed and studied which is valid for any family of distributions with increasing failure rate on the average (IFRA). It is compared, asymptotically, with a distribution-free procedure proposed by Rizvi and Sobel. Author (TAB)

Review: This paper is quite mathematical and hence the proofs will be accessible only to those with a substantial background in mathematical statistics. However, the results should be of interest to a wide variety of reliability practitioners. An obvious application is to the problem of selecting the set of "best" suppliers of some particular part.

R68-14111 ASQC 823

Boeing Scientific Research Labs., Seattle, Wash. Mathematics Research Lab.

GENERATING ASSOCIATED RANDOM VARIABLES

James D. Esary and Frank Proschan Jan. 1968 21 p refs

Its Mathematical Note no. 546

(D1-82-0696; AD-667169; N68-23394)

The paper defines associated random variables and applies results to reliability models involving various types of maintenance. TAB

Review: This report presents some of the latest research on the relatively new concept of associated random variables. Even the applications given in the report are rather theoretical, but the authors do promise a paper devoted to applications to maintenance models. Earlier research on this subject was presented in the papers covered by R68-13554, R68-13650, R68-13700, and R68-13735.

R68-14112 ASQC 824

California Univ., Berkeley. Operations Research Center.

MAXIMIZATION OF SYSTEM RELIABILITY WITH LIMITED RESOURCES

Lawrence D. Bodin Jul. 1967 24 p refs

(Contracts Nonr-3656(18); DA-31-124-ARO(D)-331; Grants NSF GK-1684; NSF GP-7417)

(ORC-67-40; AD-666619; N68-23190)

The optimization of system reliability of a series parallel system containing t types of components is found where the cost of purchasing the components is disregarded, a component can be assigned to more than one component position, and a limited supply of components is available for assignment. The optimal solution is found by ranking the reliabilities of the components of each type and searching over these ranks in the orders specified in this paper. Author (TAB)

Review: This report deals effectively with an important practical reliability problem—that of getting the maximum reliability out of a given system—and thus should be of interest to applied reliability research workers. The biggest limitation on the results is that only systems composed of n parallel subsystems (each subsystem being a series arrangement) are considered. Several numerical examples are presented, but, as one might suspect, for large systems the calculations necessary to find the optimal solution may be quite involved.

R68-14113 ASQC 820

THE PROBABILISTIC BASIS OF CUMULATIVE DAMAGE.

Leonard G. Johnson (General Motors Corp., Research Labs., Warren, Mich.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 133–140. 3 refs.

(A68-31416)

Discussion of the problem of assessing cumulative damage. Cumulative damage is most conveniently measured by cumulative probability of failure. A complete S-N-P (stress, cycles of life, probability) diagram is required for a complete solution to the cumulative-damage prediction problem. Approximations such as Miner's rule are valid only under restricted conditions. IAA

Review: If this paper had been presented as a mathematical theory with some potential application rather than as the answer to a maiden's prayer, it would have been better. The author slides by some of his basic assumptions by implying that their correspondence to real life is obvious. Unfortunately, their applicability is not at all obvious. If, instead of using the term *damage* for the fraction of the area under the life distribution curve which has been used up, he had used the term *kill fraction* or something equivalent, his procedure would have been clearer. What he means by damage is not damage to an individual specimen but damage to a population (thus the appropriateness of the term *kill fraction*). One way to see the distinction is to suppose that the probability density function is a very narrow distribution. Then none of the author's damage would be done to the part until near the very end of its life, even though physically this may well not be what is happening. Another thing that the text presumes is that those specimens which would fail early at a high stress will also fail early at a low stress, and so on for each portion of the life. Again, it is not at all obvious that this will be the case. If one uses the term *kill fraction* and grants some of these additional hypotheses which must be made, then the author's development is largely consistent. The only question that remains is its applicability, and that can be tested only by experiment. While much of the data the author needs, namely a complete set of P-S-N curves, may be available for some automotive parts, it is rarely available in many other situations. Therefore, this paper should not be taken in the spirit of completeness, which is easy to read into it, but should be considered as hypothetical.

R68-14114 ASQC 824; 414; 521; 771

SELECTION PROCEDURES IN RELIABILITY AND QUALITY CONTROL.

John S. Ramberg (University of Iowa, Dept. of Industrial and Management Engineering and Department of Statistics, Iowa City, Iowa).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 141–144. 7 refs.

(A68-31417)

Study of the application of selection procedures as a tool for designing experiments in reliability and quality control. An attempt is made to encourage the application of these procedures by explaining the basic ideas of the procedures and illustrating their advantages. Primary attention is given to a special case of more general formulation given by Bechhofer. IAA

Review: This is a brief expository paper on selection procedures as a tool in reliability and quality control. From the standpoint of the reliability analyst, its chief value is that of calling attention to these procedures for solving the problem of selecting the "best" population from a set of k populations on the basis of some characteristic of interest. It provides an inequality which allows a practitioner to use a standard Normal table in determining sample size. The real problem, as the author has pointed out, is not that of making the selection once the pertinent data are available, but rather the question is to determine how many observations one must take in order to be confident to some specified degree that the correct population has been selected. There is also the question (not addressed by the author) of whether the "best" population is significantly better than one or more of

the others (note that a statistically significant difference does not guarantee that the difference is of engineering significance). While this paper explains the basic ideas of the procedures, it will be necessary for those who wish to become properly informed on the details to refer to other works such as those which are cited by the author. A paper not cited, but one which suggests some applications to problems in reliability, was covered by R67-13302.

R68-14123 ASQC 821; 831
RELIABILITY OF A MULTITHREAD SYSTEM CONSISTING OF COMPONENTS WITH CONSTANT FAILURE RATES.
Erich G. Pieruschka (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Research and Development Div., Systems Evaluation Dept., Sunnyvale, Calif.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 403–411. I ref.
(A68-31432)

Discussion of a method for the computation of the reliability of a multithread system—a task which generally requires the solutions of multinominal convolution integrals. The method described is applicable to all systems consisting of components with constant failure rates. By means of the Laplace transform the convolution integrals are transformed into products of the Laplace transform of the reliability functions of the components. The products of the Laplace transforms are converted into a sum of terms with integer exponents of a single Laplace transform only. Finally, the system reliability is computed by converting the Laplace transforms of the system reliability into the system reliability itself. The main advantage of the proposed method is its simplicity in setting up the equations for determining the reliability of a complex system. Only a few formulas of elementary algebraic form are required for the calculation. The method may be computerized. Author (IAA)

Review: This paper is another one which applies Laplace transforms to computing the reliability of a complex system. In this case the use of the transforms is made simple (in principle at least) by requiring the exponential distribution for each element. An algorithm is given for writing down the Laplace transform of the system. The solving of the equations is tedious if done by hand. Several examples are given in the text, but they cannot be followed by the novice without appreciable attention and study. Not all of the complicated algebraic expressions were checked, but the method is sound.

R68-14124 ASQC 820; 420; 433; 523; 843
RELIABILITY ESTIMATES FROM RUN-OUT OR NON-FAILURE DATA USING INFORMATION THEORY.
Haresh C. Shah (University of Pennsylvania. Towne School of Civil and Mechanical Engineering, Philadelphia, Pa.
In: American Society for Quality Control. Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 425–434. 6 refs.
(A68-31434)

Study of the problem of analysis of small sample bench fatigue data. If in small sample of data, there are run-outs, (sometimes called nonfailures) the problem of incorporating the information in the final survival probabilities becomes extremely difficult, if not impossible by classical statistical techniques. The paper presents a method of information theory for incorporating such data in reliability calculations. An example is given in which the optimum sample size from the point of view of optimum run-out information is considered. The formulation is such that whenever more information in the form of failure (or nonfailure) is available, the probability distributions can be modified using information theory and Bayes' theorem. In particular, the Poisson prior distribution and the Poisson sample distribution are considered. It is shown that the minimally biased distribution, when only the run-out information is available, is Poisson. Bayes' theorem is used to obtain the posterior distribution. A method is shown by which the run-out data information and the failure data information can be combined to obtain the expected survival probabilities. Author (IAA)

Review: Several papers by the author have been reviewed previously (see R67-12952, R68-13677, and R68-14022) and the adverse comments in those reviews apply as well to this paper. Some of those papers are given as references in the present text. In this paper the author's notation is poor and not well explained. The development would be very difficult for an engineer to follow unless he had previous knowledge of this kind of treatment. No engineer should use the results of this paper without first reading the original reference by Tribus and without reading some of the previous reviews (see above) of papers by the same author. In view of the preceding comments the mathematics in this paper was not checked. The foregoing remarks are not to be taken as deprecating the principle of maximum entropy as postulated by E. T. Jaynes nor the use of Bayesian methods. They should be taken to mean that engineers should not be overly impressed by mathematical symbology and manipulations which are unfamiliar to them. They should be sure at least that they understand all of the assumptions and reasons therefor that have gone into the analysis.

83 DESIGN

R68-14086 ASQC 833; 814; 871
PRACTICAL ASPECTS OF ELECTRONIC INSTRUMENTS—COST, RELIABILITY, AND MAINTENANCE.
J. R. Hileman (Hercules Inc., Wilmington, Del.).
Instrumentation Technology, no. 5, May 1968, p. 43–47. 5 refs.

Costs, reliability, and maintenance of electronic instrumentation are considered from the point of view of the user in a chemical processing industrial organization. Both initial and installation costs for miniature electronic equipment are presented, particularly in relation to pneumatics instrumentation. While installation costs for the two types of devices are shown to be 6% of the total plant costs, it is noted that pneumatics instrumentation involves three times as much labor costs as does the installation of electronic equipment. It is predicted that electronics equipment will cost less in the future, and device reliability will increase, because of improved design. High density control panels, field instrumentation, and multiconductor electrical cables are considered in terms of overall maintenance, and mention is made of cases in which one kind of instrumentation offers advantages over the other. M.W.R.

Review: It is not difficult to tell from its tone that this paper is written by a user rather than a producer of electronic instruments. The phrase, "...these growing pains will be less frequent as electronic instrumentation matures" will be something of a jolt to many electronics manufacturers. Many of them, and their designers, are under the impression that electronic instrumentation has already matured (this is not to dispute the author, but merely to point out that differences of opinion are often caused by where one sits). The paper is generally a good one. It discusses the reliability of both electronic and pneumatic instruments in reasonably practical terms, although not in great detail. One of the most conspicuous omissions is any mention of the new fluidic instrumentation. Even though most of it is still in the experimental stages, its use appears to be growing and it will probably replace

electronics in many places where the speed of electronics is not essential. In some user companies the reliability of electronic instruments can be degraded by lack of skilled maintenance technicians, especially when pneumatics is "all they know". In discussing the life of electronics instruments per se, the author's few sentences are confusing. The definition of theoretical "half life" as "...50% of the time it takes for the unit to fail..." is not clear at all. What he meant is 50% of the mean (expected) life. Since the exponential distribution is implied by stating the failure rate (hazard rate), the life of any particular instrument is a random variable and the maximum life is infinite. Also, and perhaps more to the point, is the statement that "Anyone with field experience knows that the present solid-state electronic instruments do not reach their full potential." It should be remembered that in the author's example of a five-transistor instrument, 1% of those instruments would be expected to fail in two years, even if there were no troubles other than transistors. In making a decision about which type of instrumentation to get, electronic or pneumatic, the reader should remember that most recounting of field experience is, among other things, a highly personal matter and that emphatic proponents can be found on both sides.

R68-14089 ASQC 836

RELIABILITY SYSTEM DESIGN REVIEW.

N. Cooper, H. Ascher, and R. Einzig (Naval Applied Science Lab., Engineering Branch, Sonar Reliability, Brooklyn, N. Y.).

In: Proceedings of the NMC Third System Performance Effectiveness Conference, Washington, D. C., May 17–18, 1967. Naval Applied Science Lab., [1967], p. 113–126. 3 refs.

Reliability design review of a sample circuit and a system mode of operation are reviewed for the CX (AN/SQS-26) long-range multimode sonar system equipment. The method for performing a reliability circuit analysis and prediction as well as the functional and mathematical analysis for the BB/ODT (Bottom Bounce/Omni-directional) mode are considered. The reporting procedure consisted of three separate sections: itemized parts stress, summary and contractor comparison, and critique and recommendations. Reliability and availability requirements were tabulated for two of the system's modes of operation, and quantitative assessment was made of the degradation of system parameters. Ground rules for the development of the CX mathematical models are included; and the design review program which includes everything from the individual components to the integrated cabinets and operational modes is detailed. M.W.R.

Review: A case study concerning a reliability analysis review is presented in this paper. Its realism and scope make it worthy of serious reading by those with professional interest in reliability activity. The system under review is a complex one containing significant redundancy and on-line repair capabilities, which provides an opportunity for applying sophisticated analyses. The review was extensive and was performed by Government personnel. From a reliability management viewpoint, several aspects of the contents of this paper catch the eye. Incentive contracting was applied to reliability and availability, with the opportunity for both upward or downward adjustment of fee. There was to be a formal demonstration test. Presumably this should serve to insure contractor management attention with regard to reliability and availability design efforts. Nothing is said about the contractor's reliability analysis or review during system design, or any other features of his reliability program. The comprehensive Government review consisted of the two major tasks: (a) circuit reliability review and (b) system reliability modeling. The circuit review utilized 11.5 man-years; the additional effort for the system modeling is not noted. Since 11.5 man-years is a lot of technical effort, it seems that Government technical personnel either duplicated the reliability analysis activity of the contractor or they performed it instead of the contractor. If the Government duplicated the review, then it would seem that some sampling using much less manpower would have indicated the adequacy of the contractor's program. If the Government performed the reliability program, then it would seem that communication and time-delay problems between contractor and Government would be a serious detriment. The typical Government contractor should be vitally concerned with the inferences of this case. For instance, it involves the continuing question of what is the expected level and content of a contractor's proposed reliability program. The circuit reliability design review is described as including such criteria as derating, drift, simplification, etc. However, no indication is given as to the effectiveness of this thorough review, or of any design changes which were brought about as a result of it. The complexity of the system presented some challenges in the system reliability modeling and prediction. Some original developments were apparently made concerning performance degradation and its explicit relationship to the reliability prediction. The prediction results reportedly led to system design changes and to changes in the ground rules for the reliability demonstration tests; such changes are the payoff of a prediction. The original prediction is reported as indicating that the system had a low chance of passing the demonstration tests. A question which naturally arises is, "What was the result of the contractor's reliability prediction?" If it was about the same as the Government's, then why was he presenting a system design that had a low chance of passing a formal test, particularly since a reliability and availability incentive contract is involved? Furthermore, the ultimate operational reliability would seem to be a more important criterion than the chance of passing the reliability demonstration test. It would also seem that some measure of the uncertainty of the reliability prediction would have been desirable and useful, rather than letting demonstration test ground rules dominate. Nothing is said about this. Much of what is reported in this paper attests to progress in the reliability discipline. The technical contents of these design review reliability analyses are a far cry from just adding failure rates. It seems, however, that there is still room for improvement and increased clarity in some aspects of reliability thinking, perhaps more in management than in the technical realm. On the other hand, perhaps it is just a case of the need for improved clarity in writing a paper.

R68-14090 ASQC 831; 824; 844

MACHINERY RELIABILITY STUDY.

J. I. Schwartz (Naval Ship Research and Development Center, Annapolis, Md.).

In: Proceedings of the NMC Third System Performance Effectiveness Conference, Washington, D. C., May 17–18, 1967. Naval Applied Science Lab., [1967], p. 143–155. 1 ref.

Reliability is considered as a design parameter, and computation of system reliability is discussed in relation to a steam propulsion plant. It was assumed that the propulsion system consisted of all the machinery required for the propeller to rotate and maintain rotation for 15 knots for 6000 hours in calm seas, and system failure was defined as inability to meet propeller rotation in the desired direction and at the desired speed. Reliability programs for the overall system as well as for some of the subsystems are discussed, numerous reliability diagrams are included, and a reliability equation is given for the propulsion system as a whole. Results presented are considered a mathematical exercise until accurate failure rate data on ship machinery components become available, although reliability analysis techniques are considered applicable to the design of ship machinery systems. A simplified form of the Bayes' theorem is detailed, and applied to both a two-element series system and a switched redundant circuit. M.W.R.

Review: It is encouraging to see the application of reliability analysis to an increasing number of commodities. This paper is

concerned with a single-screw steam-propulsion subsystem. The essence of the paper is the development of a reliability logic model and there is enough diversification of types of redundancy to make this interesting. The paper gives the impression of a good start with room for increased sophistication. In justifying the reliability study, the only cost factor which is introduced is that of reduced boiler maintenance costs, which would come about from an increase in reliability. This brief remark only serves to open the door to a cost-effectiveness type of analysis. The increased reliability would have some additional cost associated with it and there may be cost savings other than that of reducing boiler maintenance costs. For example, any significant increase in reliability of a subsystem such as this one would increase the availability of the vessel, which for a number of such vessels, would essentially amount to having more vessels available for operation. A reliability logic model is developed, and no maintainability factors are explicitly included. The realism of this type of model is questionable, as it seems to lead to an unrealistically low reliability. For instance, when numerical values are inserted into the model, a reliability prediction of 0.91 for a typical mission is obtained. This does not seem realistic for a "must" subsystem like propulsion. It could come about possibly because the numerical values which are inserted are unrealistic and/or because of an unrealistic model. No comments are given in the paper as to the sources of the numerical values. This is an interesting topic for a mechanical subsystem where nonexponential failure time distributions might be expected. It would seem that the reliability model should consider the possibility of on-line repair, because if a redundant item which is failed can be repaired before the other redundant items fail, then a great increase in reliability can be obtained. The reliability model is described as being based in part on Bayes' theorem and the Appendix consists of some additional material on this. There is some confusion arising in part from the confusion on the testbook (Bazovsky, "Reliability Theory and Practice," Prentice-Hall, New York, 1961) which is referenced in this paper. The pertinent rationale here is that of applying the basic laws of probability and not of Bayes' theorem per se. See R65-12019 for further discussion of this point.

R68-14097 ASQC 832

Bunker-Ramo Corp., Canoga Park, Calif. System Effectiveness Lab.

A FURTHER STUDY OF USE OF HUMAN FACTORS INFORMATION BY DESIGNERS Final Report, 16 Sep. 1966–15 Mar. 1967

David Meister and Dennis J. Sullivan 16 Mar. 1967 100 p refs

(Contract Nonr-4974/00/)

(AD-651076; N67-28604) CFSTI: HC$3.00/MF$0.65

The study was performed to verify an earlier investigation which concluded that designers had little or no interest in human factors information and usually failed to apply human factors criteria to design. Ten designers from the Douglas Aircraft Company were presented with 3 4-hour tests in which they were required to develop equipment drawings, solve design problems analytically, rate the importance of design parameters, use MIL-STD-803 and similar documents, and review human factors handbook material. The general conclusions resulting from the earlier study was verified. Design analysis involved primarily the equipments mechanical/electrical functioning. Subjects showed little interest in or ability to apply human factors data to their design problems. Internal components and equipment structure determined the selection and arrangement of controls and displays. Human factors was not recognized as a distinct discipline, nor were human factors problems in design recognized as such. There was almost no use of human factors specialists to resolve such problems. As was found in the earlier study, human factors information in handbook form is not acceptable to designers because of its academic mode of presentation and because much of the material is non-applicable to design problems. Much of the material in human factors standards is not considered to be mandatory in controlling design.
Author (TAB)

Review: This report is a sequel to the one covered by R68-13940, describing an effort to verify the results of the earlier study which had suggested that designers had little or no interest in human factors. A different group of designers from a different industrial setting was used in the present study. In addition, the goals were broadened to include consideration of (a) the usefulness of military human engineering standards and (b) the adequacy of popular human engineering handbooks. The conclusions make clear the need and opportunity for human factors specialists to improve their contribution to the design function. Suitable recommendations for accomplishing this are made by the authors. At the same time it must be kept in mind that human factors is one of many considerations which impose constraints on the designer, and its relative importance must be kept in perspective. The report is a quite detailed presentation of the methodology used and the results obtained, together with the conclusions and recommendations. Tasks are described in Appendix A and a suggested format for human factors handbooks is given in Appendix B. The report will thus be quite useful to those with a detailed interest in human factors in relation to design. For those with a more casual interest, or an interest only in the principal conclusions, the first four pages of the report present a readable summary of these. Designers, for example, may wish to read the summary and conclusions with a view to assessing the adequacy of their own consideration of human factors. Reliability engineers can profit from reading at least parts of the report because of (a) the pertinence of human factors to reliability, and (b) the opportunity to learn something about techniques of really communicating with designers.

R68-14101 ASQC 832; 821

Applied Psychological Services, Wayne, Pa. Science Center.

DEVELOPMENT OF PERFORMANCE EVALUATIVE MEASURES

William Miehle and Arthur I. Siegel Dec. 1967 51 p refs

(Contract N00014-67-C0107)

(NR-153-177/7-5-66; AD-663161)

Logic is described for a technique that uses technician "confidence that a defect exists" for maximizing the probability of malfunction recognition. Based on parallel thinking in signal detection theory, the technique considers the job activity to encompass a host of mental acts involved in the maintenance and trouble-shooting of avionics equipment. Operator characteristics were derived for a variety of distributions of confidence, with relationships given for continuous distributions of confidence and for the discrete case considering both single and double criterion levels. Implications of these studies for training and post-training evaluation are noted; and the possibility of a programmed learning technique or another type program to allow individual technician training on acceptance criterion level setting is postulated. The employment of the acceptance level setting behavior of technicians as a fleet performance criterion is considered tenable. M.W.R.

Review: A mathematical study of the problem of maximizing the probability of malfunction recognition is described in this paper. The specific reference is to the maintenance and trouble-shooting of avionic equipment. However, the approach will be of interest to those who are concerned with assessing the reliability of man-machine systems. These include manned spacecraft, the overall reliability of which depends in part on the ability of the human crew to recognize and deal with malfunctions. The paper is a quite comprehensive description of the technique, and references are cited to related work.

R68-14102 ASQC 831; 612

A PROCEDURE FOR INVESTIGATING THE RELIABILITY OF COMPLEX LOGICAL CONTROL SYSTEMS BY STATISTICAL SIMULATION.

B. B. Buyanov, L. B. Groysberg, S. M. Domanitskiy, V. M. Ozernoy, Ye. D. Kharlamova and N. V. Shmaylo

Engineering Cybernetics, no. 4, 1967, p. 61–63. 3 refs.

Statistical simulation of complex logical control systems is discussed, and a procedure proposed for determining system reliability combines accelerated simulation with analysis of the consequences of component failures. Faulty operation and actual failure of the system to operate are considered, and mention is made of using a series of tests to determine reliability of the system. An actual case involving statistical simulation of a system with more than 6000 logical elements involved 15,000 tests of the system using 15 hr time on a Minsk-12 digital computer. Processing of test results required approximately 30 manhours. M.W.R.

Review: This paper presents a rather brief description of a Russian approach to the statistical simulation of a complex system for the purpose of reliability evaluation. Readers who do not have a prior knowledge of statistical simulation are unlikely to get much out of the paper, and those who do will find little that is new to them. Thus the paper serves only as a brief illustration of a Russian approach to this problem.

R68-14105 ASQC 833

PYROTECHNIC ACTUATION.

H. G. Watson (Space Ordnance Systems, Inc., El Segundo, Calif.). and F. B. Pollard.

Space/Aeronautics, vol. 47, May 1967, p. 101–110. 8 refs. (A67-29304)

Account of developments in explosively actuated devices having hair-trigger, yet infallible, detonation sensitivities in high-energy charges deliberately made inert to 1000°F and 100-ft drops on concrete. A large part of the recent progress has come from new designs which owe a great deal to recent refinements in both theory and modern instrumentation. High-speed records, rapid pressure and temperature measurements, accurate calorimetry, and a wide range of tools of analytical chemistry have played a decisive role in aerospace pyrotechnics. As applications are expanded by the use of more inert pyrotechnics, there arises the need for higher and usually-concentrated initiating energy to set them off reliably. One approach now under development uses a laser source to supply pulses of firing energy through glass fibers. In this way, no electrical connections need run anywhere near the laser-energized explosive device. IAA

Review: As the authors of this paper point out, there is a widespread and expanding use of explosively-actuated items in spacecraft. Many precise and delicate tasks are being accomplished pyrotechnically with man-rated reliability. In addition, pyrotechnic devices as sources of energy have very favorable weight/energy/cost ratios. There is thus a need for designers of aerospace vehicles to be aware of the nature and capabilities of these devices. There is also a need to overcome the unfavorable image that pyrotechnics have had, i.e., that they are unreliable and hard to control. This paper will serve both of these needs, for the novice as well as for those with some acquaintance with pyrotechnic devices. It describes the basic types, their functions, applications and explosives used. It is a compact, well-illustrated discussion which contains a wealth of information for those who need to know something about these devices. Also included is a brief discussion of the problems caused by electromagnetic interference, including both static electricity and radio-frequency effects. For those who desire more detail, the selected bibliography given at the end of the paper will be useful.

R68-14106 ASQC 838; 873

COMPUTER PARTITIONING IMPROVES LONG-TERM RELIABILITY IN SPACE.

Michael Ball and F. H. Hardie (International Business Machines Corp., Federal Systems Div., Electronics Systems Center, Owego, N.Y.).

Space/Aeronautics, vol. 47, May 1967, p. 114–116, 118. (A67-29306)

Examination of evidence that computer partitioning improves long-term reliability in space. A navigation computer for an extended manned space mission poses two reliability problems: during relatively short "time-critical" phases of operation, no transient or solid computer failure can be tolerated, and during the remaining "long-term" phases of operation, both transient and solid failures can be tolerated, provided they are repairable. The effect of these requirements on computer design was explored recently. The result was a new configuration for a spaceborne computer, using triple modular redundancy (TMR) and electric functional partitioning, thus achieving the required time-critical reliability. Its long-term reliability is insured by electric partitioning into "replaceable" modules, each of which can be switched out of the data path and replaced by a spare that is switched in. IAA

Review: This is a very brief paper, describing the use of triple modular redundancy in order to achieve necessary reliability of 0.999999 for a 10-hour critical phase and 0.9994 for a 90-day long-term phase mission in an onboard guidance and navigation computer. The design involves the partitioning of the computer into (a) reliability modules, (b) replaceable modules, and (c) diagnostic modules, together with the use of majority voter circuits. The concept of long-term reliability which is employed is essentially a form of maintainability, involving the replacement of failed modules by switching the failed module out of the data path and switching in a spare in its place. Fault diagnosis is carried out by the computer itself. The paper will be of interest to those concerned with configurations for spaceborne computers, and who have background knowledge in this field. No references are given.

R68-14107 ASQC 830

FAILURE SAFETY IN V/STOL OPERATIONS.

James Hayes, Paul H. Kesling, and Norman E. Nelson (Lockheed Aircraft Corp., Lockheed-California Co., Rotary Wing New Design Div., Burbank, Calif.).

National Aeronautic Meeting, New York, Apr. 24–27, 1967, 1 paper. Meeting sponsored by the Society of Automotive Engineers. New York, Society of Automotive Engineers, Inc., [1967], 5 p. SAE Paper 670349

Concepts of safe-life, fail-safe, and failure safety are considered in the design of rotary wing aircraft, particularly in relation to airline-type operations. Methods employed by a major developer of V/STOL craft include component condition monitoring to indicate impending failures and component design so that initial failures will not be catastrophic. Better flight safety conditions are provided by safe life testing using fatigue loading spectra that conservatively duplicate flight loading spectra. Initial failures that are readily determinable in flight are not permitted to compromise alternative flight modes that may limit the operating envelope. Minimum design fatigue life of the airframe is set at twice the anticipated service usage to take care of extremely high loads, differences in maintenance procedures, and extreme environmental effects. Damage tolerance is designed into the airframe compatible with damage that is either immediately apparent to the crew or damage that is normally found only during routine inspection procedures. M.W.R.

Review: This paper is a general discussion of some of the philosophies used by personnel at Lockheed Aircraft Corporation in considering the designs of new rotary wing aircraft. Because of

this paper's general presentation, it will be of only casual interest to engineers presently working in the field of reliability. Most of the concepts would be considered "old hat" to many designers. The authors use the somewhat ambiguous terms "safe life," "fail safe," and "failure safety," evidently assuming that all designers are familiar with them. For the benefit of less specialized readers, these terms should have been defined explicitly. The authors have presented an interesting comparison between "safe life" and "failure safety," and it is unfortunate that the lack of explicit definitions detracts from its value. In their conclusions the authors state that "The records already developed by the three large urban helicopter airlines demonstrate better safety than fixed-wing aircraft in spite of their mechanical complexity." This is a rather broad statement which probably should be further qualified; for example, does this record, established by the helicopter airlines, include all accidents, as compared with all accidents of fixed-wing aircraft, or does it compare only those accidents which were caused by some mechanical failure? There is obviously quite a difference, due to the different modes of operation of the two types of aircraft and the consequent different exposure to accident situations, not to mention the various ways of computing a safety index.

R68-14122 ASQC 838; 825; 831; 872

OPTIMIZATION OF HARDWARE REDUNDANCY IN SPACE COMPUTERS.

Narsingh Deo (California Institute of Technology, Jet Propulsion Lab., Flight Computers and Sequencers Section, Pasadena, Calif.). *In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions.* Milwaukee, American Society for Quality Control, Inc., 1968, p. 389–396. 8 refs. Abridged.
(Contract NAS7-100)
(A68-31430)

Discussion of an efficient and sophisticated design for a digital computer in space, taking into account the long life required and the severe constraints on the weight and power of the computer. The need to take the demand pattern and usage period into account is indicated. The results of the first phase of research directed toward the goal of achieving maximum reliability from a given amount of hardware are presented. IAA

Review: This paper contains the proofs referred to in R68-13743, which covered the author's reference 8. (The author's reference 7 was covered by R67-13241.) Not all of the algebra in this paper was checked but it appears to be accurate. As in one of the earlier papers, the exact criteria for failure when the redundancy is even is not explained, although it is undoubtedly implied by some of the theorems (that is, one could work backwards to see what the assumptions must have been). It would have been much easier, of course, for the author to have stated them. Two implicit assumptions are (a) all failures are statistically independent and (b) good/bad is a sufficient description of any element. It is wise to make these assumptions explicit, so that they do not get lost in the shuffle. Only perfect voters are considered and the author blithely says it is straightforward to carry out the calculations for non-perfect voters. While that is true, it is undoubtedly tedious. Furthermore, there is no guarantee that, with imperfect voters, increasing the number of elements to be voted upon will actually increase the reliability. The discussion on partial redundancy is adapted from the references mentioned earlier and, as stated in the reviews of those references, this kind of analysis is worthwhile since it shows that challenges of someone else's assumptions are often fruitful.

84 METHODS OF RELIABILITY ANALYSIS

R68-14078 ASQC 844

Naval Research Lab., Washington, D. C.

METALLURGICAL FAILURE ANALYSIS OF PM-3A REACTOR CONTROL ROD LIFTING KNOB

J. R. Hawthorne, C. Z. Serpan, Jr., R. A. Gray, Jr., H. W. Watson, O. R. Gates et al 14 Jun. 1967 28 p
(NRL-MEMO-1788; AD-656579; N68-33276)

A metallurgical analysis has been performed upon a failed control rod cap from the Navy PM-3A Nuclear Power Plant. Material supplied to the Metallurgy Divison for this investigation was the lifting knob which had separated in service from the main body of the cap. The specific objective of the analysis was to determine if the material of application met design specifications and to determine the probable cause of component failure. Compositional analysis by X-ray spectrochemical and gravimetric techniques established that the lifting knob, and thus the failed control rod cap, was fabricated from a 300 series stainless steel, not from 17-4 PH precipitation hardening stainless steel as specified. Microstructural and hardness examinations further confirmed the substitution of a 300 series stainless steel for the 17-4 PH steel composition. Examination of the stem of the control rod cap knob at which failure occurred revealed severe "necking down" and heavy striations corresponding to work hardening lines. This visual evidence coupled with analytical evidence of a low strength material of application suggests component failure through gross overload. Author (TAB)

Review: This well-written case-history describes the analytical procedures and the results of an investigation into the cause of failure in a nuclear-reactor control-rod lifting-knob. The authors carried out their assigned task very well, and they show clearly that the part was fabricated from an incorrect low-strength material which failed through gross overload. The report is thoroughly documented and easy to read, but, because of the subject matter, it has little or no value as a permanent technical reference. Such analyses must be carried out, however, if future occurrences of the same problem are to be prevented and failure causes are to be established. It shows how attention to detail is important for high reliability.

R68-14079 ASQC 844

Naval Ship Research and Development Center, Annapolis, Md.

CORRELATIONS BETWEEN FLEXURAL AND DIRECT STRESS LOW-CYCLE FATIGUE TESTS

M. R. Gross and E. J. Czyryca Aug. 1967 23 p
(Rept.-2460; AD-656746; N68-33274)

Flexural and direct stress low-cycle fatigue results for six materials are compared. The materials are HY-100 and HY-140 steels, Monel-400, cast and wrought 70-30 cupronickel, and Ni-Al bronze. It is concluded that the two methods of test give equivalent results within the life range investigated when correlated on a total strain range basis. Correlations based on nominal stress are not as good because of differences between the cycle stress-strain relationships for the two types of tests. Author (TAB)

Review: The most important feature of this short report is the authors' conclusion that the results from both flexural and direct-stress low-cycle fatigue tests are equivalent, if they are compared on a total strain range basis. This conclusion is significant because flexural testing, in comparison to direct-stress testing, is simpler, requires minimal equipment costs, and is not subject to specimen misalignment and buckling. Design and test engineers may find the flexural and direct-stress fatigue curves useful as references. The report is well written and easy to read.

R68-14081 ASQC 844; 711; 712
General Motors Research Labs., Warren, Mich.
BASIC THEORIES RELATING TO FATIGUE IN METALS
John O. Almen and Paul H. Black [1968] 17 p refs Presented at the 1965 ASM Metals and Materials Congr., Detroit, Oct. 1965
(N68-88002)

Physical properties exhibited by metals subjected to fatigue loading are discussed. Fatigue fractures are considered to result from tensile stresses; and a diagram is included to show that failure due to nominal compressive stress is actually due to tensile stress. Since fatigue cracks cannot propagate in compressively stressed surfaces, beneficial effects of shot peening and other surface cold working are, therefore, due to the residual compressive stress rather than work hardening. Surfaces of metals are much weaker than the subsurface metal. Plastic yielding occurs at much lower stresses under fatigue loading than under static loading; and because plastic changes occur in fatigued specimens, the stress range can only be stated in nominal terms. The Goodman effect is considered the result of residual compressive stress that develops from tensile plastic yielding when the applied tensile stress exceeds the dynamic elastic limit. The source of residual stresses that cause the Goodman effect is also the source of the changes in stress range, reduction or increase in magnitude of stress, and reversal of residual stress from compression to tension or tension to compression. M.W.R.

Review: This paper is essentially a restatement of sections from a published book—"Residual Stresses and Fatigue in Metals", McGraw-Hill 1963, by the same authors; therefore, it provides little that is new. Editorially the paper could be improved with better organization, the addition of appropriate subtopics, and a more descriptive title. There are inconsistencies in the paper which range from insignificant mistakes to serious errors of judgment. The "proof" that the surface of a material is weaker in fatigue than the subsurface metal should be expanded. In the presentation of the theory that fatigue failures are tensile failures, a residual stress distribution and a maximum and minimum applied stress are assumed. Based on this assumption of a maximum tensile stress of 35,000 psi and a maximum compressive stress of 215,000 psi are calculated, and the discussion is continued with the statement: "However, the maximum applied tensile stress occurred at the surface where, because of the lower residual stress near the surface, we may assume that the tensile stress was nearer 60,000 psi." Additional explanation of this statement is required for complete comprehension. Furthermore, it would appear that an adjustment in the maximum compressive stress value (from 90,000 to 60,000 psi) is required. The term "material properties" is used rather loosely in the paper, and the authors list the following "newly discovered properties of metals": (1) fatigue fractures propagate by tensile stresses only, never by compression; (2) the surface of metals is much weaker in fatigue than subsurface metal; (3) the beneficial effects of shot peening and other surface cold working operations are due to residual compressive stress, not to work hardening; (4) under fatigue loading, plastic yielding occurs at much lower stresses than under static loading; and (5) because of plastic changes in fatigue specimens during testing, the stress range can be stated only in nominal terms. These might more logically be called hypotheses or conceptual models about fatigue. The statement: "...hardness is a state of stress..." is difficult to understand because it is quite possible to have two materials or specimens with the same hardness but in different states of stress. The paper will be of interest to those who are familiar with the senior author's contributions to the practical engineering knowledge of fatigue and residual stresses. A shortened edited version of the paper appears more recently under the same title in *Metals Engineering Quarterly*, Vol. 6, February 1966, pp. 9–15.

R68-14087 ASQC 844; 821
EQUATIONS FOR FRACTURE MECHANICS.
K. E. Hofer, Jr. (IIT Research Institute, Chicago, Ill.).
Machine Design, vol. 40 Feb. 1, 1968 p. 109–113.
(A68-18576)

Brief examination of the fracture-mechanics approach for predicting whether a crack or flaw in a metal alloy will cause failure. Some fracture-toughness values of a number of common alloys are presented, and the stress-intensity factors relevant in 21 cases of alloys (in the form of sheets, beams, bars, or plates) with cracks or flaws are derived. IAA

Review: This is a brief but well-done paper which deals with a very complex subject —fracture mechanics. The author lists several simple fracture equations which he has identified with various crack geometries and load conditions. He has tabulated material constants along with the equations, so that the paper can be used to predict reliably whether a crack or flaw will ultimately result in a failure. The paper is a useful reference for design engineers, reliability engineers, and quality control personnel. Because of its simplicity and completeness, personnel involved with customer complaints may find the document useful to illustrate mathematically that a crack or flaw is not critical and that the part can be used without concern for failure. Fracture mechanics is a rapidly-progressing field that will continue to have a good impact on the discipline of Reliability.

R68-14088 ASQC 844; 821
Toronto Univ. (Ontario). Inst. for Aerospace Studies.
STATISTICAL ASPECTS OF COEXISTING FATIGUE FAILURE MECHANISMS IN OFHC COPPER
P. J. Haagensen Jun. 1967 81 p refs
(Grant NGR-52-026-008)
(NASA-CR-66424; UTIAS-TN-112; N67-30863) CFSTI: HC $3.00/MF $0.65

The results of a series of axial load, constant amplitude fatigue tests at zero mean stress on oxygen free, high-conductivity (OFHC) copper specimens are presented. A total of 631 specimens were tested at four stress levels near the lower "knee" of the S–N curve. The log normal (Gaussian) and the Weibull (extreme value) distribution functions were fitted to the complete sample of test endurance data at each of the four stress levels. A combination of two log normal distribution functions and a combination of a log normal and a Weibull distribution function were also applied since at all stress levels a two mode single, or bimodal distribution representation appeared feasible. Author

Review: This document is statistically oriented; therefore some general knowledge of statistics is required to understand it. Because of the overall statistical character of the paper, it would probably be of greatest interest to reliability and fatigue test engineers, even though design engineers have to be aware of the statistical nature of fatigue. The author makes two separate statements concerning the intended purpose of his investigation: (1) "...to check the existence of bimodal endurance distributions on sound statistical basis," and (2) "...aimed at determining the endurance distribution as a material property, ..." These two purposes are not necessarily the same; and it would appear that this work was directed towards item (1). Material and material conditions would undoubtedly have an effect on endurance distributions. For example, hardened 52100 steel would probably have a different distribution than annealed OFHC copper. The paper is easy to read and well documented. The statistical techniques were not checked in detail, but they appear to be correct.

R68-14091 ASQC 845
FAILURE RATE DATA COLLECTION AND USE.
R. Moore (Naval Fleet Missile Systems Analysis and Evaluation Group, Corona, Calif.).

In: Proceedings of the NMC Third System Performance Effectiveness Conference, Washington, D. C., May 17–18, 1967. Naval Applied Science Lab., [1967], p. 201–220.

The Failure Rate Data (FARADA) program, jointly sponsored by the Army, Navy, Air Force, and NASA, provides services to these and other government activities as well as to more than 300 contractors and educational institutions engaged in development or construction of military and space equipment. Objectives of FARADA are to improve overall system and component reliability, utilize existing data for reliability and maintainability prediction, reduce technical data research time, aid logistics planning, and conserve human and other resources. Operating procedures of FARADA are discussed, including its organizational setup and center and its sources of information. Forms used to disseminate FARADA-collected data are shown, and contents of the Failure Rate Data Handbooks are noted. M.W.R.

Review: An overview of the FARADA reliability data program is given in this well-illustrated paper. This program, sponsored by the Army, Navy, Air Force and NASA, is a model of industry-government cooperation for the mutual benefit of all participants. The four-volume FARADA series is essentially an expansion and modernization of the sort of information found in the old work-horse, MIL HDBK 217A. Maximum contractor participation in this program is desirable, and information on this is included in the article. The report covered by R68-13968 is concerned with a recent study of Volume 1 of this program.

R68-14092 ASQC 844

AVOIDING SECOND BREAKDOWNS IN POWER TRANSISTORS.

Will Steffe and Tom Moutoux (Fairchild Semiconductor, Mountain View, Calif.).
The Electronic Engineer, Dec. 1967, p. 65–69. 4 refs.

Most of the unexplained failures in power transistors are attributed to secondary breakdowns in which output impedance has changed instantaneously. A hot spot forms and distortion occurs at the same time, followed by reduced beta and device operation at currents above the specified limits. Avoidance of hot spots by including negative feedback within the transistor is discussed; as are reverse biased avalanche failures, pinch-in failure and its prevention, and emitter protection. The use of emitter resistors, appropriate choice of lateral and vertical structure, and control of the high resistivity collector region are considered necessary to the design of power transistor devices with predictable dissipation. M.W.R.

Review: While the entire spectrum of second breakdown in power transistors is briefly reviewed, the emphasis in this discussion is on "pinch-in" (a reverse-biased emitter crowding effect that concentrates current in the center of the emitter region) and on the use of series emitter resistors to lessen the second breakdown mode that accompanies "pinch-in". The authors' prose does not always communicate; particular criticisms are the following. (1) The reader who does not already understand the positive feedback cycle of a power transistor will probably still not understand it after reading the authors' explanation on page 66. (2) The discussion following the heading " 'Pinch-in' Failure" contains the following unclear sentence, "Since the collector width is fixed by the thickness of the high resistivity region, an increase in base width will decrease the available collector depletion width and therefore lower the maximum sustaining voltage." The authors indicate in the private communication that this statement can be understood by reading the paper by C. T. Kirk, "A Theory of Transistor Cutoff Frequency (f_t) Falloff at High Current Densities" in IRE TRANSACTIONS ON ELECTRON DEVICES, Vol. ED-9, pp. 164–174, March 1962. The physical electronics described by the authors is hard to follow throughout, and without an understanding of the physics, the major points of the paper cannot be fully appreciated. The user of transistors—power transistors in particular—will perhaps put the paper down with the reassuring feeling that second breakdown limitations are being overcome by the manufacturer, even though he will not know why.

R68-14094 ASQC 844

SOLDER BALL FORMATION AT THE SCREENED GOLD-SILICON INTERFACE.

George L. Duggan (Sylvania Electric Products, Woburn, Mass.).
Solid State Technology, no. 6, Jun. 1968, p. 42–44. 3 refs.

Solder balls or solder climb formed at 370°C at the screened gold-silicon interface in a gold paste conductor ink used in die bond operations was attributed to the formation and spreading of a gold-silicon eutectic; and the mechanical steps required to eliminate this formation are reviewed. Surface temperature of the substrate was decreased to below that used for die bonding to gold plated kovar. This slowed diffusion rate and, consequently, amount of eutectic formation. The power level of the ultrasonic die bonder was decreased to the point where eutectic formation between silicon chip and gold was initiated, so that no additional ultrasonic scrubbing was required for eutectic formation. When the truncated collet used to scrub the chip was not parallel to the substrate, the eutectic material was forced out along one edge of the chip. Placement of this collet absolutely parallel to the gold on the substrate was necessary; and collet height was adjusted to run flush with the gold surface because excessive pressure on the gold during eutectic formation was considered a major factor in causing solder climb along the edge of the chip. M.W.R.

Review: The use of thick screened gold films to form intraconnects between Kovar package leads and bonded wires as well as mounting pads for silicon chips is a combination that many manufacturers have probably considered for meeting the package demands of LSI. This paper reports that while the combination is compatible, a problem, identified as the formation of solder balls composed of the 97%–3% gold–silicon eutectic, can arise in die bonding to thick screened films of gold. The problem appears to be of the nuisance variety; improved technique solves it, although the author's recommended procedures are not necessarily unique. The terms "headermounting" and "die bonding" are apparently used interchangeably for no obvious reason.

R68-14095 ASQC 844

THE EFFECT OF TRANSISTOR COLLECTOR DESIGN ON OPERATING VOLTAGE AND SECOND BREAKDOWN.

B. Reich (Army Electronics Command, Electronic Components Lab., Fort Monmouth, N. J.).
Solid State Technology, no. 6, Jun. 1968, p. 49, 50. 1 ref.

Various types of silicon planar epitaxial and triply-diffused transistors were examined to determine the effect of transistor collector design on operating voltage and secondary breakdown. With an optimum collector design, particularly with regard to the width and resistivity of the epitaxial or intrinsic region, it is considered possible to operate transistors in the common emitter open base configuration up to the collector-base breakdown voltage. For the devices studied, all housed in TO-5 packages, this was noted for pulse widths up to 300 microseconds. M.W.R.

Review: The gist of this brief note is that certain types of silicon planar epitaxial and triple diffused transistors exhibit one of three relationships between BV_{CEO} and BV_{CBO}. In two of these relationships $BV_{CEO} \approx BV_{CBO}$ and the author concludes that this desirable characteristic can be obtained by judicious choice of collector doping and spacing. Little *detail* is given; the prime purpose of the communication is to draw the reader's attention to

the above observation. The examples used suggest that the result is more a decreasing of BV_{CBO} to BV_{CEO} rather than a build-up of BV_{CEO} to BV_{CBO}, so that the operating range of the transistors is about the same. The questions then arise in the reader's mind, "Does this relationship always hold?" "If so, what voltage range advantage does this type of behavior offer?"

R68-14109 ASQC 844; 833
FATIGUE ENDURANCE AND CREEP OF GLASS FIBER-FORTIFIED THERMOPLASTICS.
John E. Theberge (Liquid Nitrogen Processing Corp., Product Development, Malvern, Pa.).
Modern Plastics, no. 10, June 1968, p. 155–158, 160. 8 refs.

Flexural creep, tensile stress relaxation, and fatigue endurance data are presented for a series of high moduli (> 1,000,000 psi) glass fiber-fortified thermoplastic resins. These include polystyrene, polycarbonate, polysulfone, polyacetal, polypropylene, nylon resins, and PVC. Effects of stress, glass fiber content, and base resin on creep resistance and fatigue endurance were investigated; and an empirical correlation was observed between long-term creep data and short-time tensile stress relaxation data. Glass-fortified thermoplastic resins are less stress-dependent than the unreinforced resins, the viscoelastic limit of many of such resin systems approaches the yield strength of the base resin, and large increases in resistance to cyclic stresses can be obtained by glass-fortification. A relative ranking of the strength of these resin systems for use in applications with a great many fatigue cycles indicates nylon-6/6 > nylon-6/10 = polycarbonate > polyacetal > polypropylene > polysulfone = polystyrene. M.W.R.

Review: This kind of paper on the design properties of materials is useful to designers who are trying to make high-reliability equipment. Unfortunately, however, there is absolutely no indication in any of the properties what the scatter would be. In the fatigue curves especially, one can presume that they are median curves but few designers want to design near the median life or median strength. One ordinarily wishes, of course, to get appreciably below the 1% level. Thus, while this information is certainly better than none, it is still not complete. Furthermore, and this is something not mentioned in the article, the properties of plastics are quite sensitive to the molding conditions, so that these tables should be taken as only a rough guide.

R68-14115 ASQC 844; 755; 851
QUALITY ASSURANCE AND RELIABILITY (TOTAL NONDESTRUCTIVE TESTING).
Richard B. Socky (General Electric Co., PMP Engineering, Philadelphia, Pa.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 156–167. 16 refs.
(A68-31419)

Examination of the concept of total nondestructive testing now being implemented by industry. The underlying principle is that, to provide genuine effectiveness, nondestructive testing must start with the design of the product and end only when the product, used by the customer, performs correctly for satisfactory period of time. Product flow is examined in its entirety. IAA

Review: This paper appears to be a summary of a more complete report which was not referenced, or it may be a synopsis of the references cited. As a survey or summary report on nondestructive testing (NDT), it mentions most of the known techniques, and thus is very useful for the initiated reader but not the newcomer to NDT. A number of special techniques which appear to be quite useful were omitted. They include (but are not limited to) the following: magnetic resonance, ultraviolet (black light) exposure to specially treated surfaces for analysis of strain, radiographic analysis which does not require the use of film (recently developed for use in industry... much like fluoroscopy) and can be monitored individually or in groups via television-type screens, nuclear radiation using isotopes and tracing their flow through the process, extreme temperature treatments which permit ready visibility of surface and subsurface defects (most popular is the freezing method). One question arises which may be due to the brevity of the description for each technique, and that pertains to the inclusion of 'vibration' as an NDT method. Generally, it is considered a destructive test and the paper does not describe how it is used as an NDT method. In his list of references the author failed to mention one major source of information on infrared testing, namely the work of Riccardo Vanzetti (see, for example, R63-10993, R65-11978, R65-11991, R65-12126, R67-13151, R67-13234, R68-13603, and R68-13713). With these minor reservations this paper is excellent as a compendium of NDT methods and is useful as a check list for the experienced practitioner of test programs.

R68-14116 ASQC 844; 775; 851
NONDESTRUCTIVE TESTING IN A NEW DIMENSION.
G. J. Posakony (Automation Industries, Inc., Boulder, Colo.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 183–188. 4 refs.
(A68-31420)

Evaluation of the current transitional phase of nondestructive testing (NDT). It is concluded that the use of NDT will not grow through the development or exploitation of new energies, new equipment, or new methods. Further research will deal rather with methods such as radiographic and ultrasonic methods, and methods based on the use of magnetic particles, penetrants, eddy currents, optics, IR, microwave, and strain gauges to evaluate materials in a nondestructive way. IAA

Review: This easily-read paper presents nondestructive testing (NDT) methods in the light of current cost of doing business when maintenance costs rise, safety problems multiply, and delivery problems require solution. The author presents NDT in a difficult transition period and is pleading with his fellow specialists to get on with the development of new methods to keep up with the state of the art. Education is needed, and he encourages the audience/readers to contribute to this endeavor. An excellent reference chart is included in the paper (Tables 1A and 1B), listing the defect type being sought and the test method available to produce the results needed. While the paper is very short, the message is plain, viz., NDT has not been used to its fullest advantage nor will it be so used until the NDT experts start to keep up with the state-of-the-art in materials and processes and above all attempt to apply NDT techniques early in the design process. (Other papers on NDT are found on pages 156, 479, and 501 in the same Transactions.)

R68-14120 ASQC 844; 520; 720; 831; 833
ASSURING INTEGRATED CIRCUIT RELIABILITY DURING PRODUCTION.
David I. Troxel (Radio Corp. of America, Defense Electronic Products, Communications Systems Div., Camden, N. J.) and Bernard Tiger *In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions.* Milwaukee, American Society for Quality Control, Inc., 1968, p. 347–354. 5 refs.
(A68-31427)

Experience with integrated circuits on many equipment development programs along with study programs to specifically investigate their characteristics has produced considerable information pertaining to integrated circuit reliability. In a study of monolithic silicon integrated circuits, for the Rome Air Development Center, the principal investigations consisted of Stress Survival Matrix Test (SSMT), a Test to Failure (TTF), and a Physical Effects Analysis (PEA). The findings of this study indicate the nature of a new approach to reliability prediction. This approach is based on screening effectiveness, identification of quality related failure mechanisms, probability of occurrence of each failure mechanism, and the resulting environmental susceptibility and life distribution of the units containing each respective failure mechanism. These same fundamentals serve as the basis of a test and analysis approach, applied during integrated circuit production, to assure that the current production units achieve their reliability objective. Author (IAA)

Review: This paper references the one by the same authors covered by R68-13838. The present paper is somewhat different in that (a) it is shorter and (b) one of the sections (Production Control) is expanded somewhat over the original paper. All of the figures appear to be the same except for an additional table which shows an application for Reliability *Assessment*. The review of the original paper is applicable to this one with the additional comment that keeping track of failure mechanisms and modes for the purpose of controlling production as well as predicting reliability is a good idea. Many of the recommendations seem to fall in the class of "belling the cat" or "putting salt on the tail of the bird to catch it".

R68-14125 ASQC 844; 341; 710; 864

COMPONENT RELIABILITY AND FAILURE PATTERNS IN MILITARY SYSTEMS.

Theodore L. Tanner (Bell Telephone Labs. Inc., Whippany, N. J.). *(Tagung über Technische Zuverlassigkeit Nuremburg, West Germany, 1967.) (Technical Reliability in Individual Presentations,* no. 10 [Technische *Zuverlässigkeit in Einzeldarstellungen,* no. 10], Munich, R. Oldenbourg Verlag, 1967, p. 43–52. In German.) *In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions.* Milwaukee, American Society for Quality Control, Inc., 1968, p. 435–441. 1 ref. (A68-30644)

Descriptions of several American electronic systems characterized by high reliability. Failure and replacement data are given for some military ground systems, the transatlantic telephone cable, and several aircraft electronic systems. IAA

Review: This is a concise and very worthwhile paper which discusses some of the underlying causes of component replacements in military systems. Referring to one of his earlier papers (see R66-12526), the author mentions the very low component-replacement rates which are being achieved in modern electronic systems. In view of this, the good suggestion is made that the most reasonable way to obtain data on replacement rates is to monitor the failures in operational systems having large numbers of components. This is more realistic than extrapolating from the results of accelerated testing conducted in laboratories. The importance of adequate failure reporting procedures to achieve this purpose is noted. It should be emphasized that replacement rates and failure rates are not the same thing. The study reported in this paper pertains to experience with electronic components in the following three areas: (1) digital portions of ground-based military systems, (2) undersea telephone cable systems, and (3) missile-borne electronic systems. The data on replacement rates are given in a graphical form which enables easy assimilation of their salient features. Such accumulation of information on what can and does go wrong is essential to the avoiding of past mistakes and the enhancement of the reliability of future systems.

R68-14085 ASQC 844

Seattle Univ., Wash. Dept. of Mechanical Engineering.

THERMAL FATIGUE DAMAGE UNDER A TWO-STRAIN-BLOCK HISTORY Final Report, 1 Jul. 1963–1 Jul. 1967

Harry Majors, Jr. Jun. 1967 110 p refs

(Contract DA-31-124-ARO(D)-145)

(AROD-4116-1-E; AD-656481; N67-36911)

Thermal-strain fatigue, two block strain cycling, axial tension-compression tests were performed on thin-walled tubes of annealed, type 200 nickel to study the plastic strain damage process that leads to failure in the range of 10,000 to 100,000 cycles at a mean temperature of 580F under a frequency of 60–90 cycles per hour. Plastic strain ranges are in the order of twenty to forty per cent of the total strain range. All tests showed a transient period in the first 100 cycles prior to the stress-strain hysteresis loops stabilizing. A cumulative damage theory was developed which led to the relationship for a two-strain block history. Author (TAB)

Review: This is a final report for a four-year project on thermal fatigue. The author has reviewed the state-of-the-art, presented additional experimental data, developed a cumulative damage theory (the validity of which must be proved for other materials and test conditions), and suggested several additional areas of investigation. The document is lengthy and difficult to understand because of the rather complicated mathematical treatment, which was not checked in detail by the reviewer. The report is well documented with graphical and tabular data and numerous references to the technical literature. But because of the complexity and the length of the paper, it is not recommended for general reading. Engineers that are designing elevated-temperature components from type 200 nickel may find the experimental data useful. Senior scientists and research engineers working in this area may find the report to be a useful reference.

85 DEMONSTRATION/MEASUREMENT

R68-14119 ASQC 851; 200; 345; 770; 780

MULTI-STATE CLASSIFICATION SAMPLING PLANS—AN EXPERIMENTAL APPROACH TO ACCELERATED LIFE TESTING.

N. C. Pavacich (Bell Telephone Laboratories, Inc., Quality Assurance Center, Holmdel, N. J.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 335–345. 1 ref.

(A68-31426)

Discussion of an acceptance life-testing procedure involving the use of what have been termed Multi-State Classification Sampling Plans. The procedure is intended to be used jointly by the component designer, the manufacturer, and the consumer to discharge their respective responsibilities with regard to life performance. The results of a life test performed at regular intervals on a prescribed sample of product units are used to classify the product represented by the sample into one of four predetermined states, each one corresponding to a certain interpretation of the character of life performance and of the manufacturing process

with known risks of misclassification. Interpretations regarding life performance, the shipment of product, corrective action, economic implications, and the risks of misclassification with regard to each of the states are covered in detail. IAA

Review: This seems to be a good plan, and if it works as well in practice as the paper implies, then it is indeed an excellent plan. The emphasis in this discussion is on the engineering aspects of the plan rather than the statistical calculations, and thus it can be followed easily by engineers. It is the kind of test planning that can be adapted to many different situations, even those in which designer, manufacturer, and customer have not cooperated in setting the limits. This cooperation phase is a good idea where it can be done. Where the customer is not a part of the same conglomerate, it may not be possible to get his cooperation, but one ought to be able to get the designer and manufacturing groups to cooperate always. Anyone who wishes to institute such a plan will eventually have to get the services of a statistician in order to make a few of the calculations; but in general this will be the least of anyone's concern since setting the original numbers is likely to be a time-consuming, argumentative, and thus expensive, task. In a private communication the author has stated that "My experience indicates it is less expensive to have complete understanding of what constitutes an acceptable acceptance test program serving the needs of all parties concerned than to debate the issue after any one party discovers he is getting results that are not compatible with his needs. This is true whether that party be the consumer, designer, or manufacturer." All in all, this is a good paper and its contents should be considered by all of those who are concerned with sampling plans and outgoing quality. One point the author brings up but does not pursue is the question of shipping before the tests are complete. If the tests seem to be going well, the shipment is made; but if this judgment is later reversed by the end of the test, there is no indication of what is supposed to happen. The author has added the information that one should find the failure mode, its apparent cause, its effects on end use of the product, its effects on the future product and the time to correct the process. After that, (a) the manufacturer should recall the shipment, inform the consumer to reject outright with arrangements being made for rebate or replacement, or (b) the consumer should accept the product on a nonconformance basis for a specified time interval with or without eventual replacements, and/or (c) the designer should take steps to improve the design.

R68-14121 ASQC 851; 817

MTBF PRODUCTION SAMPLE PLAN TESTING VERSUS 100% SYSTEM CYCLING AND RUN-IN TESTING.

F. Philip Klein and Allan S. Golant (Electronic Specialty Co., Los Angeles, Calif.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 363–373. 9 refs.

A complex, multi-box, airborne electronic system containing more than 6,000 discrete parts was subjected to both periodic MTBF production sampling audits and 100% system cycling and run-in tests. Advantages of the latter to both customer and contractor are noted, and a 50-hr period eliminated nearly all of the failures. While costs of the system cycling and run-in tests were greater than sampling plan costs, the 100% screening tests reduced modes and numbers of failures per set of equipment. In addition, 100% screening enabled a more regular delivery schedule, and avoided some of the inventory costs in holding finished equipment pending completion of sampling tests. Other advantages of the cycling and run-in testing are that it pinpoints needs for further component-level screening from the data on repetitive system-level failure modes, and allows more corrective action by the contractor prior to delivery to the customer. M.W.R.

Review: This paper is very difficult to read, but it presents a reasonable question as to the validity of sample plan testing to determine MTBF for acceptance purposes as compared to a full system cycling and burn-in test program. The economic justification and the possibility of having a test present results more unfavorable than the actual performance are two real circumstances which could cause misery to many an organization. The method of presentation leads this reviewer to wonder whether the authors were looking for "a way out" because of technical considerations or only because of economic concern. In either event, the paper is not convincing, nor does it offer the reader justification for further study. In fact it presents some contradictions not fully explained. This paper is not one to be used for indoctrination of newcomers to the field of reliability, as it will serve to confuse more than to enlighten them.

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RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 11

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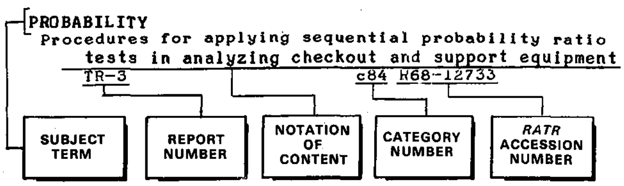

The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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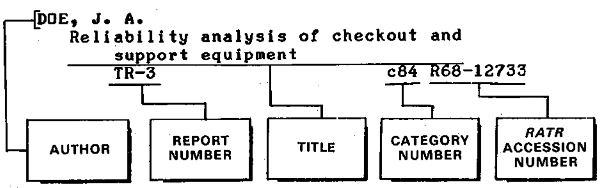
PERSONAL AUTHOR INDEX

Typical Personal Author Index Listing



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REPORT AND CODE INDEX

RELIABILITY ABSTRACTS AND TECHNICAL REVIEWS VOLUME 8 NUMBER 11

List of Report Numbers

This may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number preceded by the category number for locating the abstract-review in the abstract section of *RATR*. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB, STAR,* and *IAA,* respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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NASA-Langley, 1968

Reliability Abstracts and Technical Reviews

DECEMBER 1968

Volume 8
Number 12

R68-14126—R68-14175

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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The second section of *RATR* contains four indexes: The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed in the journal; this index also includes a listing of the ASQC codes for identifying the *RATR* accession numbers of the items to which the codes have been assigned. The Accession Number Index identifies the categories in which the abstract-reviews appear in the journal. Cumulative indexes are published annually.

EXAMPLES OF CITATIONS IN *RATR*

RATR ACCESSION NUMBER → R68-12733 ASQC 844; 413 ← ASQC CODES
General Equipment Company, Banville, Calif. ← CORPORATE SOURCE
TITLE → RELIABILITY ANALYSIS OF CHECKOUT AND SUPPORT EQUIPMENT
AUTHOR → John A. Doe 23 Sep. 1966 27 p refs ← PUBLICATION DATE
CONTRACT OR GRANT → (Contract NAS15-13411)
REPORT NUMBER → (TR-3; AD-629305; N68-15098) ← *TAB* AND *STAR* ACCESSION NUMBERS
CFSTI: HC $3.00/MF $0.65 ← SALES AGENCY AND PRICE

RATR ACCESSION NUMBER → R68-12739 ASQC 814 ← ASQC CODE
TITLE → SEMICONDUCTOR RELIABILITY
Joseph A. Smith (Eastern University, Arlington, Penn.) ← AUTHOR AND AFFILIATION
JOURNAL REFERENCE → *Electric Journal*, vol. 8, Apr. 1966, p 478-492.
(A68-12569) ← *IAA* ACCESSION NUMBER

RATR ACCESSION NUMBER → R68-12765 ASQC 773; 221; 823 ← ASQC CODES
TITLE → TESTS OF SYSTEMS WITH SOME DEPENDENT FAILURES
Joseph A. Smith (Eastern University, Arlington, Penn.) and B. James White (General Equipment Company, Banville, Calif.) ← AUTHORS AND AFFILIATIONS
CONFERENCE OR SYMPOSIUM REFERENCE → *Association of Reliability Engineering, Failure Rate Conference, Olney, Tex., Mar. 13-17, 1966, 8 p*
Available from Assoc. of Reliability Eng., New York: $1.00 ← AVAILABILITY AND PRICE
IAA ACCESSION NUMBER → (A68-12407)

VOLUME 8 NUMBER 12

Reliability Abstracts and Technical Reviews

A Monthly Publication

of the National Aeronautics and Space Administration

December 1968

81 MANAGEMENT OF RELIABILITY FUNCTION

R68-14128 ASQC 813
National Airlines, Inc., Miami, Fla.
AIRCRAFT STRUCTURE RELIABILITY PROGRAMS
H. J. Young 2 Nov. 1966 16 p Presented at FAA Maintenance Symp., Washington, 2–4 Nov. 1966
(AD-667143; N68-85913)

The overall aircraft structure reliability program of a commercial air carrier is reviewed by relating the means for its implementation in maintaining a complete fleet of aircraft. Maintenance control by applying reliability methods to aircraft structures is the emphasis of the program which uses a block overhaul inspection system as its primary source for knowledge about the aircraft structures. Periodic servicing provides additional means of observing structural conditions, as does continuous surveillance by a number of company and FAA personnel. The importance of recording data and communication through the various levels of maintenance and control are among the other topics covered in this speech, which also notes some of the specific documentation methods used.
M.W.R.

Review: This is a very enthusiastic paper which gives a qualitative description of the aircraft structure reliability program of National Airlines. It is readily understandable and almost anyone will be able to see the broad outlines of the program by reading the paper. Programs such as this are apparently effective since most failures that do occur in the airlines are ascribed to other causes. At the end of the paper the author's use of the analogy of a chain's being no stronger than its weakest link becomes confusing when he shows how it applies to the maintenance program but not to the aircraft itself. In a private communication the author has indicated that he meant only "to show that although the link-chain analogy seems appropriate at first glance, when discussing operating systems reliability, the redundancy of contemporary aircraft systems and the incorporation of fail-safe design has made the vehicle far more reliable than the 'chain'." He has also stated that the air carrier industry (including National) relies heavily on the open forum approach to its problems for solutions and for program improvements. (In reading any such paper as this which describes an important company program, the reader should remember that very little dirty linen voluntarily gets washed in public and therefore one never really knows for sure whether success is because of or in spite of the program, or whether there are any unsatisfactory points which are being ignored. These parenthetical remarks are not meant to denigrate this paper in any way, but merely to point out an area of ignorance that exists for the reader.)

R68-14141 ASQC 815
ANATOMY OF A RELAY SPECIFICATION FOR MILITARY APPLICATION.
Carl B. Knox, Jr. (Babcock Electronics Corp., Babcock Relays, Specification Engineering, Costa Mesa, Calif.).
In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967, Proceedings. Conference sponsored by the Oklahoma State University and the National Association of Relay Manufacturers. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 5–1 to 5–21. 9 refs.

Relay specifications are considered in terms of meeting intended military applications, and need for proper documentation of these specifications is stressed to avoid errors and misunderstandings. Attention is given to the relay purchase order, the detailed and general specifications, military specifications and standards, and manufacturers' catalogs. Mechanical, electrical, and environmental parameters related to relay specifications are surveyed. Visual and mechanical inspection are among the mechanical parameters, as are relay configuration, marking, surface finish, contact chatter and form, and terminal strength. Coil resistance, operate/latch and release/reset values and time, contact bounce time, dielectric strength, and insulation resistance are among the electrical parameters. Others are contact load and resistance, duty cycle, and overload. Environmental parameters discussed are vibration, shock, acceleration, high-low temperature, thermal shock, leakage rate, salt spray, and contact life. Sampling plan, tolerances, and acceptance and qualification testing programs are considered.
M.W.R.

Review: The voice of experience permeates this comprehensive overview of relay specifications in the military environment. The comparison tables and checklists which are presented will be of handy reference value. Such words as reliability and quality do not appear very much, but their achievement is the implicit goal of nearly every feature of these specifications. Table 2 in the paper, titled "Relay Symposium Information", is a cross-reference of typical specifications requirements and Relay Symposium Proceedings papers—another handy information retrieval aid. This paper is

potentially useful both to the relay specialist and to other engineers. A point for such readers to keep in mind is that the author is associated with a relay manufacturer and thus it is likely that biases, if any, will tend to favor the manufacturer's viewpoint.

R68-14144 ASQC 813; 844; 851
RELAY RELIABILITY—A TEST AND ANALYSIS PROGRAM.
Charles L. Buckner (ARINC Research Corp., Annapolis, Md.), and Ivan J. Soper (USAF, Logistics Command, Wright-Patterson AFB, Ohio).
In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967, Proceedings. Conference sponsored by the Oklahoma State University and the National Association of Relay Manufacturers. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 8–1 to 8–10. (Contract AF 33(601)-9074)
(A67-27698)

Description of an approach used in a reliability evaluation of electromechanical relays, with discussion of test equipment, data acquisition, and data analysis. The purpose of the program was to obtain information on the reliability of the relays that will have the greatest demand within the Air Force during the next ten years. Primarily, the relay reliability information will consist of contact life as a function of contact load. To determine this, a life test was designed that included several different load types and current levels. Preliminary results indicate that the contact failures follow an exponential distribution. IAA

Review: This program seems to have two purposes, (1) to find the ways in which one can most reasonably accelerate a test for relays and (2) to use those methods to estimate the reliability of a particular class of relay. More of the first purpose than the second is accomplished in these tests, and it is noteworthy that the data in many cases are so sparse that their appropriate distribution is not yet obvious. For example, in some cases it is not yet possible to distinguish between the exponential, the Normal, and the log-Normal distributions. A further difficulty will arise in assuming that these acceleration factors will hold for other relay types and styles. Regardless of how adaptable these results will be to other relays, the reporting of them in the open literature is worthwhile, so that those who do run other kinds of tests can compare their results with these. Hopefully, there will eventually be a wide body of knowledge to show what engineering factors are important and what kinds of acceleration are possible for several kinds of relay application.

R68-14148 ASQC 813
National Aeronautics and Space Administration. Manned Spacecraft Center, Houston, Tex.
GEMINI RELIABILITY AND QUALIFICATION EXPERIENCE
W. Harry Douglas 1967 36 p Presented at the NATO Advisory Group for Aeronautical Res. and Develop., Guidance and Control Panel Symp., Paris, 7–8 Mar. 1967
(NASA-TM-X-60372; N67-37043) CFSTI: HC$3.00/MF$0.65

In optimizing the reliability and qualification program, emphasis was placed on establishing high inherent reliability and low crew-hazard characteristics early in the design phases of the Gemini Program. Stringent numerical design goals for mission success and crew safety were placed on the contractor who incorporated these goals in each specification written for flight hardware. Design reviews were conducted by engineers to insure unbiased evaluations and were completed prior to specification approval and the release of production drawings. Redundant systems or backup procedures were provided where a single failure could prove catastrophic. A closed-loop failure reporting and corrective action system was adopted which required the analysis, determination of the cause, and corrective action for all failures, malfunctions, or anomalies. The integrated ground test program consisted of development, qualification, and reliability tests conducted under rigid quality control surveillance. The application of these criteria to the guidance and control system is discussed. M.G.J.

Review: This type of presentation is suitable for program managers and others who have a feel for the detail of what a program would involve once they are given the broad outlines. Even though the crew safety on this program was perfect, some of the submissions were not successful. These two facts should be kept in mind if the report is read. The organization of the Reliability/Quality effort appears to have been sufficient, i.e., the people who wanted to do a good job were encouraged to do so and those who were disposed otherwise would have their disposition modified in a desirable direction. Those who have not been responsible for managing programs should realize, however, that organization and structure do not do anything, it is only people who do it, and that one forgets this at his own peril. There is considerable use in the paper of the phrase "inherent reliability," which tends to be ambiguous. One of the best interpretations for it is: the reliability that would be achieved if the designer could exclude any failure which he felt was not his fault. A paper such as this performs a useful service in giving program managers a chance to see what others are doing.

R68-14155 ASQC 817; 831; 843
USING COST DATA TO OPTIMIZE RELIABILITY.
Kendall Weir (Radio Corporation of America, Defense Electronic Products, Communications Systems Div., Camden, N. J.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 491–499.
(A68-31438)

Outline of methods amenable to computer solution for generating system reliability models and optimizing them with respect to another system parameter. A simple reliability model which represents a nonseries, parallel, or series-parallel configuration is considered in order to demonstrate the optimization technique. Although the discussion is restricted to optimization of the cost variable, weight, schedule, or volume could have been chosen as easily. IAA

Review: This paper is mathematically consistent and thus when the assumptions are applicable the method will give good results. The paper itself is reasonably straightforward. In the section on computer modeling, the author's notation is awkward, i.e., it is very easy to confuse the event with the probability-of-that-event using the author's nomenclature. (Therefore the novice should be very careful. It would have helped, for example, if small letters instead of large ones had been used for the events.) This kind of problem has been treated elsewhere in the literature, usually from the point of view of redundancy. Again, the novice should not be misled by the kinds of formulas for reliability versus cost of the elements since the limitations on those formulas are not explicit. There is an upper limit to the cost that can be put in because at that point the reliability is 1. Only in reliability regions below about 0.9 are such simple formulas likely to be adequate. Above 0.9 the costs tend to increase appreciably as the reliability gets closer to 1. In general the basic premise of the paper (spend resources where they do the most good) is not arguable and the careful reader can profit from the author's illustration of this principle.

R68-14157 ASQC 816; 351; 864

DOES CORRECTIVE ACTION PREVENT DEFECTS?

Robert L. Cooley (Burton Research Laboratories, Los Angeles, Calif.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 593–600. 10 refs

Corrective action is often undertaken to help control product value and product costs because the customer demands these considerations; but, it is stressed, that corrective action must also be an integral function of quality control so that defects during production can be minimized. Contractual requirements for corrective action in MIL-Q-9858A, NPC 200-2, and DSAM 4155.3 are noted; and difficulties in implementing corrective action are indicated in the cases of a high voltage rectifier bridge and a high reliability diode are noted. M.W.R.

Review: This is a loose paper which starts off on corrective action between supplier and customer, drifts off to "within-company" corrective action systems and then to those between the customer and his customer—primarily the government. The author condemns "corrective action by committee," and describes a sequence of individual actions followed by a meeting to resolve differences. The condemnation of committees is not justified or explained in the text. The examples selected are excellent but the request for action was at fault, and not the supplier or the system. The most important point made in the paper is that it takes a *big man* to carry out this *big job* of directing a corrective action program, as there are many sources of frustration. The paper is replete with references which would be considered as general background but do not particularly add substance to the thesis that corrective action must be carried out in order to have a successful QC program. The form given as an example is useful.

R68-14158 ASQC 812; 123; 322; 351; 352; 720; 760

VENDOR–VENDEE TRAINING FOR RELIABLE SOLDERING.

R. L. Cutright (General Electrodynamics, Garland, Tex.) and C. L. Carter (C. L. Carter, Jr., & Associates, Inc., Management & Personnel Consultants, Dallas, Tex.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 607–611. 4 refs.

Training, motivation, and qualification of personnel is considered the key for producing acceptable quality, reliability, value, and integrity for any products or services; and a program for training and qualifying wiring and soldering inspection and associated personnel is reviewed. Selection of instructors, training equipment requirements, and tools for the trainees are considered; and eye, dexterity and related medical tests are noted. A general outline is presented for a five-day course for wiring and soldering technicians. M.W.R.

Review: Training for solderers in all industry is certainly a commendable idea. The references cited were all prepared by the author's organization; breadth would have been achieved by including some of the other documents on the subject such as the NASA NPC 200-4, the more recent NHB 5300.4(3A) (May 1968), BuWeps OP2230, MIL-S-6872, as well as some of the many published articles. The paper consists primarily of the outline for a five-day training course for potential solderers. The outline is brief, and more than likely the instructor would be expected to describe the results of poor workmanship in order that the worker may fully understand the task he is being trained to do. Experience has taught us to tell the reasons why one is expected to do certain tasks in a particular manner. Another area of omission in the outline is that the worker may not be told how to handle the results of his work, packaging, the use of tools for bending leads, the effect of the wrong cleaning fluid, the reaction of time on solder and soldered items, the methods of repair, rework, etc. These items could very probably be sub-topics; therefore there is a great deal of preparation work yet to be completed before a training course can be offered which will result in a long-term good solderer. Soldering is a vital step in electronics, and reliability is dependent on excellent workmanship by the individual doing the work. He should also be acquainted with methods of flow solder, drag solder, and dip soldering, all of which have their place and value. The operator who is training in various methods, their advantages, disadvantages, prime uses, costs, etc., can help avoid problems in production and take advantage of peculiarities in manufacture. The reader is urged to read the outline with the understanding that the sub-topics need to be developed as well as examples of good and poor workmanship before the course is ready for the trainee.

R68-14159 ASQC 810; 341; 762; 764; 840; 853

DEFECT MANAGEMENT BY EXCEPTION.

Keith W. Moburg (Ideal Industries Inc., Quality Control, Sycamore, Ill.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 685–690.

A three-step procedure for record keeping and analysis was developed that uses the principle of management by exception for in-process inspection and quality control functions. Examination of inspection records over a one-year period revealed that 80% of the forms indicated few or minor numbers of rejected lots; and the existing forms showed that the products with the most problems were least amenable to analysis and proper reporting. The three-part form, Inspectors Report on Defective Materials, that was developed emphasized reasons for defects. The first part was the inspector's report, the second went to production control and then to manufacturing, and the third to quality control. All of the information from one was carbon copied on 2 and 3, and the first part remained in the inspection department file. Production control used its copy to determine if replacement parts were needed and manufacturing used the information obtained as an alert to the problems involved. The overall process required much less paper work than was previously required, and permitted quicker decisions by the inspection chief. M.W.R.

Review: Congratulations to this author for discussing the cost versus record keeping practices of Quality Control-Reliability engineers. This paper should be required reading for all QC and Reliability supervisors. The reading exercise might awaken some dormant thoughts about current systems. Although there are other ways of solving the problems presented, the author makes the reader think. This paper along with the one starting on p. 715 in the same Transactions should enable the development of a sound system for least cost and maximum utility. The author notes that paper work record keeping occupies the inspector for about 12% of his time; but it actually may sometimes run as high as 40%. The system suggested can be improved upon and is probably effective at the author's organization, but others should study its suitability and make any necessary modifications before trying it in their organizations. There are other shortcuts which might be valuable, such as preprinting the route sheet or receiving report with the "rubber stamp" format to save time; identification of details such as supplier, lot, date, item, would not have to be repeated as they would already be on the document. The accept or reject data could be on all forms and the routing and filing need not change. The accounting function now retains most of these data for the audit functions—why create another file on those items which are completed? Nevertheless this thoughtful paper is worth the time to read it with an open mind—your costs could be reduced.

R68-14160 ASQC 810; 340; 760; 840; 853
DISCREPANCY REPORTING AND CORRECTIVE ACTION SYSTEM SIMPLIFICATION.
H. H. Mishler (General Dynamics, Convair Div., San Diego, Calif.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 715–725.

A "one write-closed loop" program was developed for simplification of discrepancy reporting and better corrective action procedures. The form provides improved management controls and visibility, reduces costs and errors in data, and results in data standardization and a central data storage bank. Many illustrations indicate the contents of the reporting procedure, which can be initiated as an action request, problem report, functional test request, or inspector's report. All departments at the industrial plant participate in the reporting program; and reliability control has responsibility for total program effectiveness, program management, and data analysis. M.W.R.

Review: The author was so intent on simplification of a reporting system that he carried his thesis to the paper and made his written portion so brief that it is difficult to see how he justified some of his decisions. The idea is good...simplify...and the system described appears to be simple. Using the system proposed by the author along with the philosophy described in the paper on reporting to management by "exception" beginning on p. 685 in the same Transactions would probably be very economical for all organizations. The combination would involve collecting *all* data, but taking action and reporting on only the special exceptional items. This constitutes good and economical use of the data and paper work. No references are cited, but the author in a private communication has indicated that none were used. He has also stated that the system has been applied successfully on NASA contracts, is simple, cheap, flexible and a good tool for management. The most valuable portion of the paper is the illustrations, as they make a wonderful chart talk for management briefing. All Reliability and Quality Control personnel can use help in selling their management, and these charts are useful for that purpose.

R68-14161 ASQC 815; 350
WHAT FAULTY CONTRACT PACKAGES DO TO US.
Ronald E. Brence (Defense Contract Administration Services, Philadelphia, Pa.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions Milwaukee, American Society for Quality Control, Inc., 1968, p. 735–738.

Cooperation between government and industry representatives is stressed as the means for achieving optimal contractual arrangements and controlling quality and costs of contracted products. The need for uniformity is emphasized, as is the precise specification of requirements. Military specifications regarding reliability are reviewed, with the notation that they should be used only when the product requires such specifications. Over-specification is cautioned against as much as is under-specification of requirements. Some of the consequences of faulty contractual packages are noted, and some examples are mentioned. M.W.R.

Review: An overview of basic DoD quality requirements and identification of the applicable specifications and forms are presented in this paper. Quality and reliability workers in both Government and industry should be aware of these topics. With regard to reliability, the author notes that when reliability is important, MIL-Q-9858A should be called out. Although the introductory remarks in the paper imply a joint industry-Government effort for improved quality, the admonitions given are largely directed toward industry. The paper notes the cost to the Government of poor quality. Industry, of course, has its quality-related cost problems, some of which are brought on by the fact that the Government is a multi-voiced entity. For instance, there are always pressures on industry for lower cost and various Government quality representatives may interpret the same specifications and requirements differently. Papers such as this one by a Government representative would leave industry readers in a better frame of mind if more of the steps the Government has taken to improve its efforts were included along with indications of what industry must do.

R68-14164 ASQC 815; 351
A PROCESS CONTROL SPECIFICATION FOR INTEGRATED CIRCUITS.
William R. Rodrigues de Miranda (Raytheon Co., Communications and Data Processing Operation, Norwood, Mass.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 799–809. 13 refs.

Numerical process control by an integrated circuit manufacturer is described; and the various concepts on which such a quality assurance program is based are discussed in terms of retaining inherent reliability, screening procedures, sharing responsibility, and implementing the program. The Process Control Specification (PCS) was developed for monolithic digital IC's, but is considered applicable to linear or hybrid circuits by incorporating additional requirements. Portions of the specification discussed relate to the general requirements for materials and processes, detailed requirements for acceptable construction and workmanship, and minimum requirements for visual inspection. The historical development of the PCS is reviewed, its intended use is discussed, and efforts for insuring its compliance are noted. M.W.R.

Review: This paper describes Raytheon's Process Control Specification (PCS), a document intended to be universally applicable to the manufacture of digital monolithic silicon integrated circuits (IC's). The PCS is planned to be part of the customer's sales contract and spells out in detail those visual inspections that must be made by the manufacturer in producing such digital IC's and the criteria that are to be used in accepting or rejecting specific units. Visual inspections and rejection criteria are nothing new—every major manufacturer has his own set of color photomicrographs illustrating the rejection criteria used by both quality control inspectors and manufacturing personnel on the production line. Even the specification of visual inspection criteria by the customer—ostensibly the customer telling the manufacturer how to run his business—is not new. Major IC customers of the past on high-reliability space or missile programs have prepared specifications very similar to that described in this paper. The noteworthy feature of the present effort is its bid to be universal. The existence of different visual inspection criteria from manufacturer to manufacturer, within a single manufacturer's production line, and from one customer to the next is inefficient, unreasonable and costly. But different inspection criteria now exist because of the subjective nature of the specified criteria. (Very little documentation exists to show, for example, that a bond that is located 2/3 within the bonding pad is acceptable, while a bond that is only 1/2 on the pad should be rejected.) The criteria put forth in this paper do not change the arbitrariness of the criteria, although these specific criteria seem to have been reached by majority consensus among many manufacturers and Raytheon. Presumably these specific criteria are as good as any. The key point is that here is a set of criteria that everyone, hopefully, will use, and so far its acceptance by manufacturers has been good. A universally accepted standard is, of course, but a small step in the right direction. As the author

recognizes, the implementation of the standard is much tougher, being in the hands of fallible human inspectors. While not mentioned specifically in the paper, the next major step forward is to automate these inspections. This step is still far away; at present the task is simply to get everyone to agree on the details of what integrated circuits should look like, assuming perfect inspectors. The next step is more of a problem. The author's paper "Visual inspection of IC's boosts reliability at little cost," which appears in *Electronics*, vol. 41, 19 Aug. 68, p. 104–108 is essentially a presentation of the same material as in this paper. The *Electronics* paper is shorter, is illustrated in color, and does present the essential points of the concept, although not in as much detail as is given in the ASQC Transactions paper.

R68-14165 ASQC 810; 831
SYSTEM RELIABILITY ANALYSIS—MANAGEMENT TOOL.
Lee R. Webster (Radiation Inc., Reliability and Quality Dept., Melbourne, Fla.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 817–821. 4 refs.

A general discussion of the roles of the artisan and engineer precedes the presentation of data relating annual maintenance costs to original procurements costs of military electronics as compared to some consumer goods. Estimates of 60 to 1000% maintenance costs are given for the military electronics, while 3 to 15% are listed for automobiles, home appliances, and radio and television sets. The fields of reliability and maintainability developed in response to the need evidenced by such percentages; and a systems effectiveness approach has been developed as a technique for dealing with the numerous effects of increasing complexity of electronic equipment. The systems approach is discussed in general terms, and attention is given to the reliability analysis function inherent to systems analysis. M.W.R.

Review: This is a brief philosophical discussion of the system approach to reliability and maintainability. As such, it would serve a purpose in the general indoctrination of management personnel having responsibility for these functions. However, it does not get into the specifics of what to do and how to do it. The discussion, so far as it goes, is quite reasonable and the paper is easy to read. The talk was probably much more effective and useful to the audience than the published paper will be as an archival document.

R68-14166 ASQC 813; 830; 844
RELIABILITY ASSURANCE AND THE CONCORD ENGINES.
B. G. Markham (Bristol Siddeley Engines, Ltd., Aero Div., Filton, Bristol, England).
Society of Automotive Engineers, National Aeronautic Meeting, New York, Apr. 24–27, 1967, Paper. New York, Society of Automotive Engineers, Inc., [1967], 13 p.
(SAE Paper 670316; A67-32978) Members, $0.75; nonmembers, $1.00.

Outline of a method of deriving an engine design specifically for civil operation from a military supersonic engine. The failure pattern of current engines is studied, showing that the traditional approach to reliability must be extended. Reference is made to the application of the disciplines of reliability engineering and of the special design features to ensure safety and reliability. A description is given of the test program and of some of the special test equipment required for a supersonic engine. IAA

Review: This paper treats the engineering aspects of reliability as opposed to the statistical description thereof. The author is concerned largely with the analysis of designs for the purpose of showing up faults. For those who are not aware of this kind of engineering approach to reliability, this paper can serve as a good introduction. It does not go into great detail about any of the tests, but can help keep one up-to-date on the kinds of things that are being done in design and development of jet engines. (There is an amusing paragraph on the tests for the ability to ingest birds.) Nondestructive inspection of the engine, while in place, has been considered in design. While many of the reliability features are, of course, concerned with safety, perhaps a far greater number are purely economic considerations.

R68-14171 ASQC 814
ECONOMICS OF ELECTRON TUBE RELIABILITY.
S. A. Obolenskiy
Telecommunications and Radio Engineering, no. 5; *Part 2. Radio Engineering*, 1967, p. 137–139.

Costs of testing a single 100 kW triode and of the testing apparatus are given; and it is noted that such costs can sometimes exceed the value of the original electron tube. Mention is made of some field testing, and it is concluded that guaranteeing the life and reliability by the tube manufacturer is too costly a procedure and that a more economical testing procedure must be found. Component reliability and device reliability are briefly discussed; and the complexity of determining device reliability is noted. No reliability procedures are presented. M.W.R.

Review: The title of this paper is quite misleading. About all it says is that, for transmitting tubes, life test data based on the Poisson distribution are extremely expensive to come by, especially in terms of operating power and test set-up. Therefore, if one wishes to predict reliability for situations other than those covered by field data, one needs to investigate the reliability of the elements making up the transmitting tube. This is likewise predicted to be a difficult task—and at that point the article ends.

82 MATHEMATICAL THEORY OF RELIABILITY

R68-14134 ASQC 823; 413
General Electric Co., Schenectady, N. Y. Research and Development Center.
OPTIMUM TESTS WITH GROUPED DATA FROM AN EXPONENTIAL DISTRIBUTION
W. B. Nelson Oct. 1966 19 p refs
(Rept.-66-C-398; N67-35876)

Statistical methods (particularly useful in reliability measurement and demonstration) of treating grouped data on items having exponentially distributed times to failure are given. The maximum likelihood method of estimation for mean life is presented with tables for optimum test planning. A statistical (demonstration) test for mean life that is locally most powerful and is simpler than the test based on the maximum likelihood estimate is described. Tables for this test are provided. These methods are extended to apply to items with times to failure with a Weibull distribution with known shape parameter. Author

Review: The problem of testing hypotheses about the mean of an exponential lifetime distribution when the data have been grouped is treated quite satisfactorily in this report. Grouping of data can be an important practical problem due to discrete

inspection times, etc. It should be pointed out that the theory given is applicable only when the inspection times are fixed ahead of time, e.g., the grouping intervals cannot be random in any way. The author also states that the results are applicable to Weibull lifetime distributions with unknown location parameter and known shape parameter. Surely this is an artificial assumption in most situations, however, the Rayleigh distribution (Weibull with shape parameter equal to 2) is used in certain communications engineering applications. Furthermore the author really means scale parameter rather than location parameter. The author's argument using the Central Limit Theorem to obtain the approximate normality of a certain statistic seems rather loosely written.

R68-14135 ASQC 823; 431

Douglas Aircraft Co., Inc., Santa Monica, Calif. Missile and Space Systems Div.

MARKOV PROCESSES AND SOME AEROSPACE APPLICATIONS

G. J. Schick 22 Jun. 1967 35 p refs Presented at 48th Ann. Meeting Pacific Div. Am. Assoc. for the Advan. of Sci., Los Angeles, 22 Jun. 1967

(Douglas Paper-4588; N67-36118)

The basic properties of Markov processes are defined, and their application to decision making is shown. Models, which are probabilistic in form, are derived for the discrete and continuous Markov processes, an R-dimensional process, the Wiener process, and the Poisson process. Examples are provided to show their use in reliability equations, optimal replacement policies, physics, availability models, and industrial applications. M.G.J.

Review: This report was presumably intended as a tutorial-type paper for general scientists without too much background in mathematics or probability. In such a paper we do not expect much mathematical rigor. We should not, however, expect statements that can be very easily misconstrued and thus lead to a basic misunderstanding. Such statements are found in this report. The very definition of a Markov chain is clouded. The definition assumes homogeneity. Later we are told, "If the process is independent of time t, then the Markov chain is said to be homogeneous"; hence this is redundant and confusing. Numerous other confusing statements could be cited. A very brief historical review of stochastic processes of the Markov type is given together with an extensive (47 items) bibliography. The topic of this paper is of importance to those who are concerned with reliability and availability modelling, the determination of optimal replacement policies, etc. A tutorial paper would be useful to newcomers to this type of work, but this one does not serve that purpose well.

R68-14138 ASQC 824; 612; 831

McDonnell-Douglas Co., Santa Monica, Calif. Missile and Space Systems Div.

A UNIQUE COMPUTER PROGRAM FOR RELIABILITY MATHEMATICAL MODELLING

R. H. Kirk and P. H. Mueggler Dec. 1967 25 p

(Douglas Paper 4757; N68-36386)

To design reliability into a product the designer must have quantitative reliability criteria as he is developing his design. The reliability mathematical model is a major source of these quantitative criteria. If the mathematical model is developed manually, the quantitative criteria are usually provided too late, and the designer is reluctant to use them. Because of this situation, calculations for the failure probability analysis and the combined subsystem reliabilities of missiles were set up on a computer program designated OA28, which calculates and prints in report form a reliability analysis of any system for any given set of parameters. It presents a rapid and accurate method for evaluating the effects of design changes and the prediction of system reliability under various environmental conditions. This paper describes the OA28 program, discusses its unique features, and illustrates its application and capability. Author

Review: This is a good short report which gives as good a summary of a computer program as is feasible in such a short space. Obviously more than this is necessary in order to use the program, but this paper does show the kinds of things that one must do. Where terms are defined such as "achieved-, predicted-, and inherent-reliability" in the glossary, it should be pointed out that these are verbal approximations for what the machine actually does, and that the exact definitions should be taken from the appropriate formulas. One can then decide for himself whether he likes the names or not. The exponential distribution is generally used, which is reasonable considering all of the uncertainties that will go into the final answers. It is not clear how other distributions can be used, although it is stated that such is possible. From some of the description it is presumably possible to consider statistically dependent events, although again it is not said how this is done. As a matter of philosophy it can be argued that the mathematical model is inherent in the computer program and that all one is doing with this program is to describe elements of the model to the computer so that it can work on it. This is not to dispute the author's terminology but merely to point out that not everyone means the same thing by "mathematical modelling". This kind of computer program (while unique only in the sense that there is probably none other exactly like it) can be a valuable help for improving the reliability of equipment by providing the designer with an easy method of making the calculations. Not only are the calculations more likely to be accurate and comprehensive but, perhaps more importantly, they are much more likely to get done.

R68-14139 ASQC 823; 413

California Univ., Berkeley. Operations Research Center.

A NOTE ON TESTS FOR MONOTONE FAILURE RATE BASED ON INCOMPLETE DATA

Richard E. Barlow and Frank Proschan Apr. 1968 29 p refs

(Contracts Nonr-3656(18); DA-31-124-ARO(D)-331; Grants NSF GK-1684; NSF GP-7417)

(ORC-68-7; AD-669111; N68-36387)

Tests for exponential versus IFRA (increasing failure rate average) distributions based on incomplete data are defined and shown to be unbiased. The tests are motivated by a class of tests considered in detail by Bickel and Doksum. Tests for exponential versus IFRA distributions based on the ranks of total time on test statistics are also considered. Author (TAB)

Review: This is a rather theoretical paper as far as reliability is concerned but the results obtained should be of interest to the "practitioner." The type of incomplete data considered here is quite realistic. The results of the report are extensions of those given in the report by Bickel and Doksum covered by R68-13836. (The authors cite a paper to be published in *Ann. Math. Statist.*, 1968, presumably based on that report.)

R68-14149 ASQC 822

Washington Univ., Seattle. Lab. of Statistical Research.

A NEW FAMILY OF LIFE DISTRIBUTIONS

Z. W. Birnbaum and Sam C. Saunders (Boeing Sci. Res. Labs.) 22 Mar. 1968 20 p refs Sponsored in part by Boeing Co.

(Contract Nonr-477(38))

(TR-52; AD-667247; N68-23773)

A new two-parameter family of life length distributions is presented which is derived from a model for fatigue. This derivation follows from considerations of renewal theory for the number of cycles needed to force a fatigue crack extension to

exceed a critical value. Some closure properties of this family are given and some comparisons made with other families such as the lognormal which have been previously used in fatigue studies. Author (TAB)

Review: This report presents a very interesting new two-parameter family of lifetime distributions which was obtained from basic considerations of the fatigue process. It turns out that the lifetime random variable may be expressed as a fairly simple (non-linear) function of a Normal random variable. Moments may then be obtained and probabilities calculated using existing tables. We look forward to a promised report on estimation procedures for this new family and for applications to real fatigue failure data.

R68-14152 ASQC 824; 410; 717; 821

A METHOD FOR ESTIMATED ERRORS IN SYSTEM RELIABILITY PREDICTION.

Steven S. Tung (TRW Systems Group, Power Systems Div., Redondo Beach, Calif.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 413–423. 30 refs.

(A68-31433)

Derivation of a set of mathematical models for estimating errors in system reliability prediction. A number of methods, such as the Monte Carlo method, for estimating errors involved in failure rate or MTBF of components in the system, and incorporating these errors into system reliability prediction are presented. The final result is that a confidence interval can be determined for the predicted system reliability on the basis of error estimate. IAA

Review: This paper contains an impressive list of impressive references. The paper itself contributes little if anything which is new to the subject and, as a tutorial paper, is confused and unclear at best. The topic itself is of value and is treated elsewhere in the literature. Section III could be compressed into about two equations: (1) the constant hazard rate assumption (several assumptions which the author implies are independent of each other are logically equivalent); and (2) the second equation follows from either Taylor's series or the standard differential approach, viz., if $y = f(x)$ (where $x = x_1, x_2, \dots x_n$ and the rest of the notation is also conventional), then

$$\Delta y = \Sigma_i \left.\frac{\partial f}{\partial x_i}\right|_{\underline{x}_0} \Delta x_i .$$

At this point it would have been better to introduce the variance of Δy:

$$\mathrm{var}(\Delta y) = \Sigma_i \left(\frac{\partial f}{\partial x_i}\right)^2\Bigg|_{\underline{x}_0} \mathrm{var}(\Delta x_i) + \sum_{\substack{i,j \\ i \neq j}} \left.\frac{\partial f}{\partial x_i}\right|_{\underline{x}_0} \left.\frac{\partial f}{\partial x_j}\right|_{\underline{x}_0} \mathrm{cov}(x_i, x_j).$$

This equation assumes, of course, that the linear expansion is exact enough. The derivation for N parts in series with unequal MTBFs takes 1.5 pages and could be written in just a few lines ending with the formula

$$\frac{\Delta M_s}{M_s} = \Sigma_i \frac{M_s}{m_i} \cdot \frac{\Delta m_i}{m_i} .$$

The variance equation, assuming that the covariances are zero, would be written as

$$\frac{\mathrm{var}(\Delta M_s)}{M_s^2} = \Sigma_i \left(\frac{M_s}{m_i}\right)^2 \frac{\mathrm{var}(\Delta m_i)}{m_i^2} .$$

It would, of course, be much simpler in terms of λ's ($\lambda = 1/m$). Section IV on method of estimating errors in MTBF's clothes in mathematical sophistication the fact that estimates of the required parameters are extremely difficult to come by. As with much of the paper, this part is not always clear. Some examples of the difficulties are the following. (1) It should be noted in the author's formulas that (a) the *true* variances are called for, not *estimates,* and (b) many equations are different for estimates than they are for true values. (2) In the subsection for statistically independent errors, the statements are true regardless of the assumption of Normality. (3) Normality is invoked later in the discussion because it makes writing some equations easier, but generally speaking the engineer will not have nice, neat samples to work from. Furthermore, estimates of mean and variance can probably be made without it. (4) The Indirect Approach in which Monte Carlo is discussed is quite misleading. One cannot use the Monte Carlo method unless an actual or conceptual model exists; but that seems to be what the author is trying to find in his case. If the mathematical model does exist, the simple technique of linearization described earlier in the paper will readily yield the mean and variance. Further, it is easy to infer that the author thinks that 10,000 observations are necessary and can be done without a computer (done at least four times). A more likely number which will do more than justice to the available data would be 100 observations (ten would probably be enough) if in fact the Monte Carlo method were to be used. In summary, this paper has little to recommend it except its list of references. Engineers should look elsewhere for quantitative information on this subject.

R68-14162 ASQC 823

ESTIMATION AND CONFIDENCE LIMITS FOR A WEIBULL PERCENTILE FROM SUDDEN DEATH TESTS.

John I. McCool (SKF Industries, Inc., Engineering and Research Center, Research Laboratory, King of Prussia, Pa.).

In: American Society for Quality Control, Annual Technical Conference, 22nd Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 747–751. 4 refs.

(A68-31445)

Study of sudden-death testing, where a total of N items are randomly divided into r subgroups of size n each ($N = nr$), and each subgroup is run until the first failure is obtained. Expressions are given for the expected values of the sudden-death estimate as a function of r, n, the shape parameter β, and the estimated percentile X_p. Using these expressions, it is possible to determine a factor by which to correct the sudden-death estimator so as to estimate X_p in an unbiased way. IAA

Review: This is a mathematical paper addressed to the problem of estimating a percentile of the Weibull distribution on the basis of the first order statistics in subgroups of a sample. (The essential feature of "sudden death testing" is that subgroups of components are run on test until the first failure occurs.) The explanation is adequate for those with knowledge of the pertinent mathematical statistics, and the work is suitably referenced. An illustrative example is included. The paper was intended for ball bearing engineers who sometimes use sudden death testing to estimate the tenth percentile of the Weibull distribution of bearing failure. (Ball bearing rating life is taken to be the tenth percentile of the failure distribution.) The technique is quite simple to apply. To estimate a percentile unbiasedly one multiplies the median of

the sub-group first failures by a factor. The paper contains a table of these factors when it is the tenth percentile that is under investigation. Two other factors, when applied to the median sub-group first failure, yield upper and lower confidence limits on the percentile. Tables are given in the paper for the case where limits are applied to the tenth percentile.

R68-14174 ASQC 824
California Univ., Berkeley. Operations Research Center.
APPROXIMATIONS TO SYSTEM RELIABILITY USING A MODULAR DECOMPOSITION
Lawrence David Bodin Jul. 1967 22 p refs
(Contracts Nonr-3656(18); DA-31-124-ARO(D)-331; Grant NSF GP-7417)
(ORC-67-42; AD-669902; N68-30517)

Esary and Proschan show that a lower bound to system reliability can be found by enumerating all min cut sets in the coherent structure, connecting the components in each min cut set in parallel and joining each of these parallel subsystems in series where replicated components are replaced by identical yet independently operating components. A module of a coherent structure is a subset of the basic components of the system which can be treated as a component of the system due to their substructure topology. In this paper, it is shown that a lower bound estimate of system reliability can be derived by decomposing the coherent structure about its modules and applying the Esary–Proschan lower bound procedure to each module and then to the resultant coherent structure where each module has been replaced by a single component whose reliability is the Esary–Proschan lower bound to that module. Author (TAB)

Review: This report is quite technical and will require a good knowledge of this new area of research for full comprehension. Only those with such a background and an interest in the field will find it worth pursuing. The report came supplied with a substantial errata sheet —hopefully all copies are so equipped. (The author in a private communication has indicated that a corrected version of the paper is now available from the IBM Washington Scientific Center, 11141 Georgia Avenue, Wheaton, Maryland under the same title and report number 320–3505.) The reader interested in delving into this area should first become familiar with the reports covered by R63-10850, R67-12969, and R67-13064 and with [1].

Reference: [1] Birnbaum, Z. W. and J. D. Esary, "Modules of coherent binary structures," *Jour. Soc. Indust. Appl. Math.*, vol. 13, no. 2, pp. 444–462 (June 1965)

R68-14175 ASQC 822
California Univ., Berkeley. Operations Research Center.
CONTRIBUTIONS TO THE THEORY OF EXTREME VALUES
Robert Harris Apr. 1968 46 p refs
(Contract Nonr-3656(18); Grant NSF GK-1684)
(ORC-68-9; AD-670485; N68-30743)

Extreme value distribution laws are obtained for the lifetimes of multi-component systems with replaceable components, under various assumptions on the asymptotic relationship between number of components in the system and number of spare components. Results are given for limiting distribution laws of order statistics from nonhomogeneous samples and samples of random size, and applied to the superposition of renewal processes. An attempt is made to put extreme value theory into a general framework using the notion of a coherent structure, and some new results utilizing this idea are presented. Author (TAB)

Review: This thesis is, from a Reliability viewpoint, very technical; full appreciation of the results will require a substantial background in applied probability. Readers with the requisite background will find the material quite interesting and clearly written. The practical aspects of this research need to be presented in a further paper.

83 DESIGN

R68-14136 ASQC 836
MAKING THE MOST OF DESIGN REVIEWS.
John A. Burgess (Westinghouse Astronuclear Lab., Reactor Engineering Administration, Pittsburgh, Pa.).
Machine Design, vol. 40, Jul. 4, 1968, p. 90–95

Preparation, presentation, and documentation of design reviews are considered in terms of participation by design engineering, manufacturing, quality control, reliability, marketing, and field service personnel. Effective methods for conducting formal design reviews are described that emphasize the need for detailed preparation. The Air Force Systems Command design review cycle is given as an example, a design review planning schedule and a design checklist are included, and design review leadership techniques are outlined. Tips are offered for effective illustrations, and a dry run is recommended prior to the actual review procedure. Follow-up procedures and documentation are stressed as means to provide direction and background for decision making, as well as for the training opportunity afforded by a critique session following the design review. M.W.R.

Review: This is a good article on design reviews. The magazine in which it appears and the author's background tend to slant it somewhat toward the mechanical as opposed to the electronics area, but this affects only some of the details. It should be emphasized that not only can design reviews be held profitably at different stages in the product cycle, but at different levels of system complexity. In electronic equipment, for example, one may wish to have both the circuitry itself and the system aspects reviewed. A problem which can arise, especially in the company which tries to stay up-to-date on the very latest disciplines and technologies, is that too many people will be trying to accomplish too much in a design review. For example, how much value analysis and value engineering should be done at this stage? If a system is treated at a high level but yet in great detail it will be just too much to cover. Many of the suggestions in this article are of an administrative nature, i.e., helpful hints to the planners on how to "produce" the review so that the participants have nothing but technical problems to consider. The several check lists and tips are quite useful. Although the author explicitly remains somewhat neutral on the question of whether design reviews cost or pay, he (as well as virtually anyone else who has published on the subject) at least implies that they are a good thing and that they do pay for themselves—in some cases many times over. A similar subject that has received much less attention is a manufacturing review in which the same kinds of things are done, except that the design itself is not under consideration, but rather the way the shop plans to make the item is the topic of conversation.

R68-14137 ASQC 832; 821
ASSIGNING A VALUE TO HUMAN RELIABILITY.
Herman L. Williams (Martin Marietta Corp., Aerospace Group, Orlando, Fla.).
Machine Design, vol. 40, Jul. 4, 1968, p. 102–110. 4 refs.
(A68-33852)

Discussion of some of the important factors relating to the predicting of human reliability. Series and parallel block diagrams are discussed on the basis of such data as the exact nature of the task facing the human operator, operating steps, and criteria for correct performance. The inherent difference between dependent and independent events with respect to reliability prediction is considered, methods for setting up probability equations are outlined, and a basic review of the laws of chance is presented. IAA

Review: This article can be divided into two parts, (1) a discussion of the reliability of operators (the probability that the operators will do the correct thing) and (2) an introduction to the mathematics of probability and the corresponding association of relative frequency with the probability. The part concerned with the probability of successful operation by the operator is handled as well as can be expected in the limited space available and considering the intended readership and the unsettled state-of-the-art. As the author states, there are rarely good enough data to solve the problem as accurately as desired. Means for acquiring these data should be supported and encouraged. But even if the data are uncertain, it is wise to use them in the proper equations. It is strongly suggested that one not try to learn the mathematics of probability from this article. While it can give a rough idea of the subject, there are too many pitfalls to allow the beginner to hang on every detail. (For example, on page 104 the idea of statistical independence is not mentioned, nor is the problem of providing alternatives discussed completely. Later on, the discussion of statistical independence is handled poorly since it is implied that if there is no physical causal relationship between two events, then they are statistically independent. This is not necessarily true, since statistical independence is defined only by appropriate probability statements. Three equations are given on page 107, but it is not pointed out that they are logically equivalent—if any one of them is satisfied, the other two are automatically satisfied. At the bottom of page 105 one of the equations for conditional probability is incorrect as written since the same event appears on both sides of the vertical bar. In all such legitimate expressions the answer must be unity.) The use of shorthand notation is encouraged in the article, and in fact the same shorthand notation is suggested for two different things. Unfortunately the use of shorthand notation by non-experts is one of the major causes of going astray in the field of probability. It is not clear why all tasks no matter how complex they may be ought to be reduced to the basic series or parallel model. The implication on page 108 (if the mathematics is valid the result is valid) is unfortunate; it is extremely easy for the correct arithmetic to be done on the wrong numbers or to correctly solve the wrong problem. In summary this can be a helpful article if it is used only in a qualitative way (i.e., one should be careful about hanging on every detail of the probability theory given in the text).

R68-14143 ASQC 833; 815; 844

APPLYING RELAYS FOR RELIABLE AND SAFE PERFORMANCE.

P. N. Martin (SCM Corp., Stamford, Conn.).

In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967 Proceedings. Conference sponsored by the Oklahoma State University and the National Association of Relay Manufacturers. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 7-1 to 7-14. 19 refs.

Design of relay circuits; determination of required relay characteristics and ratings; and selection, procurement and reliability assurance of relays are considered. Misapplications that can lead to failures are noted, and recommendations of a general nature are given regarding the usual relay functions of selecting, energizing, and switching. Communication versus power practices, relay coil control, contact and load connections are discussed; and hazards in the use of double-throw contacts and shorting the power source through the arc are described along with circuit design methods to avoid such hazards. Shorts caused by contacts not operating simultaneously during relay transfer and reduction of hazards to personnel during servicing and troubleshooting are also considered. Avoidance of a low resistance path across the coil of a power relay during release and design for minimizing electromagnetic interference are stressed. M.W.R.

Review: This is a rather detailed paper which treats both some of the specific design problems for circuits, and requirements for the relay. The complete novice will have to study it carefully in order to understand the points. There are many who are not novices who should heed the warnings also. The proper application, selection, and specification of relays is often not a task that can be accomplished successfully with only minor effort. Many designers on many occasions should seek expert advice before making a final decision. Presumably the relay manufacturers are doing their part to make the relay descriptions more clear, more complete, and more accurate. One area this paper does not treat is the kinds of military specifications that can be invoked with regard to relays. That is practically an entire subject in itself and has very many pitfalls, not the least of which are some apparent (or otherwise) contradictions among the specifications. Relays can be very reliable parts of an electronic system and often will do a better job than semiconductor devices—but they must be applied properly.

R68-14153 ASQC 831; 822; 872

AN ELECTRO-MECHANICAL RELIABILITY MODEL.

J. Jenoriki and E. Demers (Computer Applications, Inc., Engineering Analysis and Design Div., New York, N. Y.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6-8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 443-454. 18 refs.

(A68-31435)

Discussion of a practical technique for estimating the reliability merits of an electromechanical system, in which the assumed or actual design stress calculations for parts can be used to determine the failure characteristics of the parts under the expected loading conditions. The reliability of the part is then a function of the part failure characteristics and the distribution that most closely approximates the part failure characteristics (e.g., the exponential, Weibull, or truncated normal distribution). System reliability, mean life, etc., can then be computed from the part reliabilities, taking into account redundancy of functions and the allowable failures for the redundant functions. A method is discussed for evaluating the effects preventive maintenance may have on system reliability. The concepts and methodology of the technique are illustrated by their application to a large power converter. IAA

Review: It is difficult to see the purpose this paper serves. The model is simply a series combination of elements, some of which have different reliability distribution functions. Use of a reliability distribution function which fits the component reasonably well is important and the paper is useful in calling attention to that fact. The use of non-constant hazard rates (non-exponential distributions) has been advocated before for mechanical and electromechanical components. Therefore the paper does not advance the state-of-the-art. As a tutorial paper, it treats worthwhile subjects, but is too brief (at best) to be of much value other than as a casual introduction. Of course, every mention of the need for care in selecting an *appropriate* reliability distribution function is useful. Since failures are presumably statistically independent, obtaining the overall reliability function for the system is simple in principle, and in practice a graphical result can be easily given if the mathematics

is not tractable. Some of the statements are open to challenge, e.g., "For parts that do not exhibit definite and definable wearout mechanisms it can be assumed that these parts have constant failure rates independent of time." The confusing part of the paper concerns the effect of preventive maintenance on reliability. The graph in Fig. 2 is not at all clear. It would appear to show the reliability of the system when there is preventive maintenance of one part. But even this is not clear because when that one part is replaced, the graph shows that the system reliability does not go up but stays the same; only its hazard rate has changed. If this graph is instead the reliability solely of a part, the graph itself is unintelligible. (Page 451 is a repetition of page 450.) The exponential approximations which the authors try to use for part/system reliability are part of the previous confused state. The authors do suggest that preventive maintenance will improve availability (at least up to a point), and this is certainly correct. The authors do not mention any of the disadvantages of preventive maintenance. For example, very often there is a temporary decrease in reliability after scheduled maintenance due to the fact that the act of servicing is actually destructive when performed by many service people under many circumstances. In summary, this paper contributes nothing new, and as a tutorial paper it has severe disadvantages.

R68-14168 ASQC 835; 720; 770; 844

ARE ENCAPSULATED RESISTANCE WELDED PACKAGES RELIABLE?

R. D. Engquist (Hughes Aircraft Co., Materials Technology Dept., Manufacturing Research Group, Culver City, Calif.).

Insulation, May, 1967, p. 35–41.

Resistance welding of electronic module packages is considered a highly reliable procedure although more critical analysis by management is recommended to coordinate efforts of manufacturing technology, production supervision, inspection techniques, inherent reliability, and end item costs. It is noted that encapsulated electronic package welds do not have to be very strong, and some experiences are offered from either mechanical or electrical testing of about 7,000 welded joints exposed to more than 500,000 joint-hours environmental testing. Materials and specimen design, welding equipment and procedures, encapsulants and encapsulating techniques, environmental test program, and shop handling are discussed. Reliability from normal weld schedules is considered, and strength distribution curves are presented for different material combinations welded with normal welding schedules on 14 different welding machines. Upper limits of failure probability are given for these materials before and after encapsulation. Variations in weld strength occurring from machine to machine are not considered to be particularly significant with respect to product reliability. M.W.R.

Review: The author of this paper delights in his occasional pot shots at reliability engineers, but has tried to present a practical approach to the problem of the reliability of welded joints. The tests and the analysis appear generally reasonable, although the derivation of Eq. (1) for calculating the critical failure strength is not given. The author is quite correct in pointing out that differences, even though they may be statistically significant, can be insignificant for engineering purposes. Unfortunately, not all welded joints are good, even though it is not too difficult to make them good. The author's point can perhaps be interpreted as meaning that it is easy to tell by a destructive sampling inspection whether or not the weld schedules are correct. If they are correct, then the fraction defective will be extremely low. The author spent a little more time than he needed in showing how the very low probabilities are calculated from the Normal distribution. The asymptotic formula (of which he used the first term) is very well known in the field of statistics. Of course, the only problem with having to use it (when the probabilities are so low) is that the distributions in practice will deviate from Normality enough to make any such calculations completely meaningless.

R68-14169 ASQC 838; 821

REDUNDANCY IN DIGITAL SYSTEMS.

F. A. Inskip (Royal Aircraft Establishment, England).

Electronic Engineering, Apr. 1967, p. 244–249. 3 refs.

Use of redundancy to improve the reliability of digital systems is discussed, along with possible ways of using redundancy at the component, functional, and higher levels. Some numerical values are presented for a system typical of a small data handling system; and attention is given to the NOR gate and its reliability, as well as to the reliability of the other components of the circuit. Method of performing a reliability analysis on the basis of transistor failures is presented, a majority voting arrangement is discussed, and quadded or quadruplicating logic is considered for applying redundancy. Assembly and testing techniques as well as relative power requirements are noted. M.W.R.

Review: Except for the introductory paragraph, this paper is the same as the report covered by R67-13220.

R68-14170 ASQC 838; 872

RELIABILITY OF COMMUNICATION ROUTES USING PARALLEL CHANNELS.

N. F. Genkina

Telecommunications and Radio Engineering. no. 5; *Part 1, Telecommunications*, 1967, p. 52–56. 2 refs.

Main reliability parameters of a communication line are described for a system composed of two parallel channels with correlated channel breaks. Statistical measurements of the time coincidences of these breaks are considered for two FM voice-frequency (VF) telegraph channels in which the measured parallel channels were the (1) channels of two VF systems multiplexing different RF systems, which had common terminals and a common cable, or (2) channels of a single VF system. The main line was roughly 6000 km long, and a break was regarded as a loss of carrier or a 2-neper or greater drop in its level. For the parallel channels found in VF systems, the dependent break coincidence factor was virtually zero, and less than 10 dependent coincident breaks were observed during a 600-hour observation period. The values of the main reliability parameters of the channels of a single VF system were virtually the same, but the high value of the coincidence factor for the channels of a single VF system indicated that a transmission time shift was required to improve reliability. M.W.R.

Review: This paper applies some simple algebraic manipulations to formulas for down-time of a particular redundant system. There are two parallel paths and the failures in each path may be (a) independent, (b) completely dependent, or (c) a combination of both. The average down-time is calculated for the cases where there is (a) no delay over path #2 and (b) some delay time over path #2. The down-time due to the completely dependent failures is, of course, reduced by the delay. In the experiments the completely dependent failures were found to be very small. This paper will appeal to only a very narrow group of engineers. None of the details of any of the derivations are given.

R68-14172 ASQC 833; 838

Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

THE INCREASE OF THE RELIABILITY AND ACCURACY OF POTENTIOMETRIC PICKUPS OF GYROSCOPIC INSTRUMENTS [POVYSHENIYE NADEZHNOSTI I

TOCHNOSTI POTENTSIOMETRICHESKIKH DATCHIKOV GIROPRIBOROV]
Z. F. Urazayev and V. Yu. Shishmarev 24 Apr. 1967 38 p
Transl. into ENGLISH from Tr. Aviats. Tekhnol. Inst. (Moscow), no. 59, 1964 p 3, 4; 111–137
(FTD-MT-65-301; TT-67-62354; AD-655363; N67-37506)

The article briefly reviews the modern theory of instrument reliability and discusses the use of potentiometers in aircraft instruments in detail from this viewpoint. It is pointed out that the most vulnerable element in a potentiometer is the electrical contact between the potentiometer winding and the wiping contact. Contact failure is the most serious reliability problem in automatic pilot instrumentation. The design of a reliable contact is therefore discussed in detail and a few design examples are described. The possibility of increasing the reliability by providing a second parallel contact is examined and its effect on the potentiometer performance and error is illustrated by specific examples. The reasons for contact failure are discussed, and the case when two parallel contacts are used, one of which is displaced with respect to the other by either one turn or a half a turn of the potentiometer winding, is examined in detail. TAB

Review: A large part of this paper is elementary introduction to engineering reliability problems associated with wire-wound potentiometers. The remainder of the paper is devoted to analyzing the departure from a straight-line response when there are two contacts on the moveable arm which are separated by a half or one turn. For most of the work done in this country with potentiometers the model being analyzed will be extremely simple-minded. But the article may be of passing interest to those who are concerned with this problem in their daily work.

84 METHODS OF RELIABILITY ANALYSIS

R68-14126 ASQC 844; 775
THE MYSTERY OF REINFORCED PLASTICS VARIABILITY—NONDESTRUCTIVE TESTING HOLDS THE KEY.
J. R. Zurbrick (Avco Corp., Avco Missiles, Space and Electronics Group, Nondestructive Test Evaluation Section, Lowell, Mass.).
Materials Research and Standards, vol. 8, Jul. 1968, p. 25–36.
(Contracts AF 33(615)-1705; AF 33(615)-2120; AF 04(694)-36)
(A68-33849)

Study by nondestructive testing of the causes of the mechanical performance variability of reinforced plastic materials prepared under apparently identical fabrication conditions. The difference between initial energy input and energy response, represented by a quantitative value uniquely related to a selected volume of such materials, is measured. The concept of material/energy interactions in these materials during fabrication is shown to be the key to solving the problem of the unexplainable variability of reinforced plastic products. Ultrasonics, low-frequency projected electric fields, microwaves, penetrating radiation, IR radiation, and light are used for providing quantitative material/energy interaction response indications in these products. IAA

Review: The descriptions of the various kinds of nondestructive techniques are useful (regardless of the material being investigated—whether it is plastic or not). They are short but sufficiently informative to give an idea of what to look for and, in a few cases, they go into details. The introductory material in this paper, especially that dealing with material-energy interactions, is too general. While it is useful to formulate problems and propose solutions in as general a form as possible (so as not to preclude a potential solution), to say that "...the energy changes according to the laws and effects known in the science of physics" is stretching things a little too far—there is a lot that is not known in physics. Also it does not consider whether detectable changes are important changes in the material condition. There is often not just one number obtained as a result of a test but many numbers and one of the difficulties is to sort out the important numbers. Some of this is explained in the body of the article, but the introduction itself is somewhat misleading and over-enthusiastic. The tone of the article is very positive and enthusiastic. There are, however, some very discouraging aspects of nondestructive testing: it does not solve all materials problems, it is not always easy to decide upon a proper technique or to find criteria for satisfactory vs. unsatisfactory material. In short, this paper is one of many summary articles on the subject and is neither better nor worse than most of them.

R68-14127 ASQC 844; 782
Navy Electronics Lab., San Diego, Calif.
COMPLEMENTARY HEATING OF DENSELY PACKAGED MICROCIRCUITS Research and Development Report Sep.–Nov. 1966
H. F. Dean 6 Feb. 1967 20 p refs
(NEL-1433; AD-650032; N67-28943) CFSTI: HC $3.00/MF $0.65

Some microcircuits dissipate as much as equivalent circuits using discrete transistors and resistors. Dense packaging and the resultant complementary heating therefore create reliability problems similar to those experienced with discrete components. Author (TAB)

Review: This short report is limited to a specific narrow topic, namely, the difficulties that (a) microcircuits get hotter than some people would like to think they do and (b) when the microcircuits are packed closely together they help heat each other. None of these results are really unexpected if one thinks about it because, as the author points out, the voltage levels are staying approximately the same for microcircuits as for conventional transistors performing the same function and the currents are not appreciably reduced (compared to the size reduction of the case). Apparently no attempt was made to measure the hot spot temperature on the chip, only case temperatures were measured. Other than the information presented above, there will not be much of value for most designers. For those who are dealing with very similar systems, some of the specific data may be helpful.

R68-14129 ASQC 844; 713
American Airlines, Inc., New York.
ANATOMY OF A STRUCTURAL REPAIR
P. C. Johnson [1966] 4 p refs Presented at FAA Maintenance Symp., Washington, 2–4 Nov. 1966
(AD-667141; N68-85914)

Repairs and their effects on aircraft operation are discussed, and various changes that can minimize the effects of repairs are noted. This can be accomplished at the manufacturing stage by providing a good detail design, taking measures to insure this design, and providing adequate and complete manuals to permit necessary repairs. Operators need a capable engineering group, drawings and stress data documents, and ability to approve their own repairs. Regulatory agencies can assist manufacturers and airline operators in developing realistic maintenance programs. Recommendations relating to the above suggestions are presented in this speech by an aircraft company representative. M.W.R.

Review: This is a good paper. It is always interesting to see how a manufacturer and a consumer of a product differ in their talking about the way the product is made. As a consumer, the author of this paper is speaking his mind rather bluntly (for a published paper) about the way the manufacturer actually performs his job. Surprisingly, perhaps, the author is reasonably straightforward about the way the customers perform some of their own jobs and how they react to certain kinds of regulations. The points made by the author are worthwhile, many are undoubtedly controversial, and some probably should be rejected. But it is certainly refreshing to see a paper written as if the author had something to say and wherein he says it. Therefore those in management positions in the airlines, in the manufacturers' organizations, and in the regulatory agencies can all profit from a reading of this paper. One important point which is made implicitly is that anyone subjected to regulation will to adjust his behavior so as to maximize his benefits under that regulation. Therefore it behooves those Federal agencies involved to adjust their requirements so that when the airlines are serving their own interests under the requirements they are also serving the interests of the public.

R68-14130 ASQC 844; 713

Delta Air Lines, Inc., Atlanta, Ga.

STRUCTURAL INSPECTIONS AND TECHNIQUES FOR OLDER TRANSPORT AIRCRAFT

C. B. Wilder [1968] 24 p

(AD-667142; N68-24778)

Inspection methods discussed include visual, X-ray, and ultrasonic inspection. TAB

Review: This is an extremely qualitative article on the subject. The word "older" in the title refers to less recent models, rather than to aircraft with many flying hours. The paper is for management personnel who are looking for an extremely simplified overview of the situation. The paper uses no jargon and can be understood readily by such people. About the only kind of knowledge they will get from it, however, is the kind that enables them, back home, to tell somebody else to get on with the job.

R68-14131 ASQC 844; 713

Federal Aviation Agency, Washington, D. C. Flight Standards Service.

FACTORS OF SAFETY AND FAIL SAFE STRENGTH CRITERIA

William J. McNair 4 Nov. 1966 9 p refs Presented at FAA Maintenance Symp., Washington, D. C., 2–4 Nov. 1966

(AD-667144; N68-86262)

Origin and use of the word fatigue in civil aviation is reviewed, as are Federal Aviation Agency regulations pertaining to safety factors and fail safe strength criteria for fixed wing transport aircraft. Strength requirements, limit load, and ultimate load are defined; and mention is made of the design maneuver load factor and gust velocities as related to fail safe systems. Maintenance inspection is discussed briefly, and the need for a uniform approach to fatigue evaluation is stressed. M.W.R.

Review: This paper obviously is not for design engineers but appears intended to give managers and other laymen a speaking acquaintance with the problem of fatigue in aircraft. Unfortunately the author uses more jargon and symbolism than many of these people will readily assimilate, so that the group of people who can profit from reading this paper will be small. The paper itself, of course, is technically competent. The only question is whether those for whom it is intended will understand it.

R68-14132 ASQC 844

Bean (William T.) Inc., Detroit, Mich.

THE -S/N- FATIGUE LIFE GAGE (APPLICATIONS MANUAL)

Romulus, Mich. Micro-Meas., Inc. Aug. 1966 45 p refs Prepared in cooperation with Micro-Meas., Inc., Romulus, Mich. 1st ed.

(AD-667155; N68-86388)

An applications manual details gage location, orientation, selection, installation procedures, and wiring for the -S/N- fatigue life gage, which is a small, bondable resistance sensor similar in appearance to a foil strain gage. The gage is placed so that its axis is aligned with the maximum principal strain and the strain gradient over the active grid area is minimized. The gage is bonded to the test part with a cement compatible with the strain levels to be experienced and the back of the gage must be dry-lapped with pumice or alumina. The simplest case of monitoring fatigue damage is discussed, as are transducer applications for the -S/N- gage and characteristics of the NA series sensor used. Data collection and analysis techniques are described for gage evaluation, calibration, and correlation; damage measurement, and failure detection. M.W.R.

Review: If this gage works as described, it can be an extremely useful device for preventive maintenance. Undoubtedly the cautions expressed about proper installation and calibration are extremely important; otherwise they would not have been mentioned. It is stressed several times that this gage measures only the fatigue crack-initiation life, not the fatigue crack-propagation life, and that this is quite different from the traditional SN curve procedure which uses complete specimen failure. Those in the fatigue business certainly owe it to themselves to try the gage to see what good it can do them, and to publish the results of their careful experiments. The author gives no basic justification for the gage's cumulating damage in exactly the way the base material will cumulate damage, so that the reader is left wondering about this point. In summary, this gage should be enthusiastically tested by a great many laboratories to see if and how it lives up to its promise.

R68-14133 ASQC 844; 716

Douglas Aircraft Co., Inc., Long Beach, Calif. Aircraft Div.

THE EFFECTS OF TIME IN SERVICE ON STRUCTURAL INTEGRITY OF OLDER TRANSPORT AIRCRAFT

R. H. Luke Nov. 1966 12 p Presented at FAA Maintenance Symp., Washington, D. C., 2–4 Nov. 1966

(AD-667151; N68-86271)

Although there is a connection between time in service and fatigue effects displayed by transport aircraft, the relationship is by no means clear-cut. The effect of flight time on structural integrity is greatly modified by operating conditions, pilot technique, and the quality of maintenance and inspection. While fatigue damage does tend to increase with time in service, proper inspection and maintenance protects the aircraft against corrosion damage, prevents excessive wear, detects and corrects minor fatigue damage, and incorporates improvements and other manufacturing recommendations. The cracks that develop during the first 20,000 to 25,000 hours of transport aircraft use are, in a majority of cases, attributed to preload conditions at the time of manufacture or a modification. A well-designed aircraft can be considered to have practically unlimited service life, and actual service life is usually determined by an economic rather than a wearout factor. M.W.R.

Review: This is a very qualitative paper which essentially says that if the aircraft are maintained properly, viz., in accordance with the manufacturer's instructions (including the spirit thereof) and

if they are piloted reasonably, they can have an almost unlimited service life. The author emphasizes that these strictures are important, and that some of the newer owners of older aircraft are not familiar with them. The discussion of the DC-3 brings to mind the quip that these days a DC-3 is an assembly of spare parts flying in close formation. This paper is easy to read and will be useful for managers not acquainted with the information contained therein. It involves a minimum of jargon.

R68-14140 ASQC 844; 775

RADIOGRAPHIC SCREENING OF RELAYS TO AMELIORATE HIGH RELIABILITY DEVICES.

J. E. Landers and M. W. Tatum (International Business Machines Corp., Federal Systems Div., Space Systems Center, Huntsville, Ala.).

In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967, Proceedings. Conference sponsored by the Oklahoma State University and the National Association of Relay Manufactures. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 3-1 to 3-6. (A67-27695)

Use of radiographic screening of relays as a means of detecting solder balls, weld expulsions, broken leads, faulty connections, misaligned structures, and cracks in can or structure not common to the design of the device. Radiographic inspection will not detect particles with densities less than that of the relay can, or show the presence of extraneous nonmetallic particles located behind internal mechanisms of greater density. The equipment and techniques which have proven effective are described. IAA

Review: The major portion of this paper is devoted to a summary of good radiographic techniques. It can be helpful to someone who is just getting started as well as to others who would like to compare their own techniques with this one. The balance of the paper deals with some criteria for rejection. These are largely pictorial examples rather than generalized criteria. Unfortunately, the pictures themselves did not reproduce too well, so it is difficult to see the alleged defect (especially since equivalent radiographs of good relays are not available for comparison). Radiographic techniques, of course, are effective and necessary but they are also usually rather expensive (estimated by the authors to be $3 per relay). Thus they are used only where the relays are quite expensive in the first place or the money is available for extremely high reliability.

R68-14142 ASQC 844

ANALYSIS OF A SPACECRAFT RELAY FAILURE.

A. J. Babecki (NASA, Goddard Space Flight Center, Greenbelt, Md.).

In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967, Proceedings. Conference sponsored by the Oklahoma State University and the National Association of Relay Manufacturers. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 6-1 to 6-7.

Fatigue failure of armature-stop arms of relays used in the OAO was investigated and a relay failure in one spacecraft subsystem is detailed. This relay was a rectangular nonlatching type, hermetically sealed in a helium-nitrogen atmosphere. A flat coined into the center of the stop arm during manufacture coupled with impact loading on the ferrule end of the arm resulted in many early failures of the flat on the ferrule side. Based on fractographic evidence that failure was propagated over a period time, either with vibration or during functional operation, the 103 remaining relays in stock were subjected to radiographic examination. Functional tests of 30 relays at 10 cycles per minute resulted in 20 failures within 3.5×10^5 actuation cycles. Of the 103 relays, 18 were rejected after X-ray because of contamination with loose solder particles or other discrepancies. Cracks appeared in the stop arms of three of five relays that were opened, all of which had undergone 5000 operating cycles during run-in at the manufacturing plant. Metallographic analysis was also undertaken. Life tests on an improved relay design indicated better results. M.W.R.

Review: This is a good case history which shows the detail required in the particular analysis by metallurgists in order to find the cause of failure. Since a brittle-looking fracture can occur from several causes, the correct cause had to be pinned down to find the appropriate corrective action. As the author suggests, this failure and its cause illustrate the extreme attention to detail required of manufacturers and customers where very high reliability is important. The customer shares the responsibility for obtaining high reliability and should write specification requirements that exemplify this awareness. It also illustrates the close cooperation that ought to exist between design, manufacturing, and laboratory groups in the company. Perhaps a failure such as this would have been caught in a design or in a manufacturing review—especially in a manufacturing review, since the designers may well have left it to the shop's discretion as to how the flat was to be obtained. There are probably many cases in mass production of inexpensive relays where this attention to detail might not be required or at least a customer would feel it was too expensive. But there are obviously many cases wherein the extra time devoted to every design would be worthwhile, if for no other reason than that the designers and shop people would become more aware of possible pitfalls.

R68-14147 ASQC 844

National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.

GROUND TRACKING RELIABILITY—A SUMMARY FROM GEMINI FLIGHTS GTA 9, 10, 11, AND 12

Ford Kalil May 1967 30 p refs

(NASA-TM-X-63030; X-507-67-197; N68-11206) CFSTI: HC $3.00/MF $0.65

This report contains data, in both tabular and graphical form, regarding the reliability of the ground network as configured for support of Gemini, in particular the down times of the various network functions such as: acquisition, radar range, radar angles, timing, telemetry, commands, spacecraft communication (voice), on-site computer, NASCOM teletype and high speed data. The down times reported are only those which occurred during Gemini flights GTA-9, 10, 11, and 12; i.e., launch to splash. The down time is that time from when the function was reported "red" until it was reported "green." The percent of time down for these various functions varied from 0.4% for the NASCOM teletype to 4.8% for the C-Band radar ranging function. Author

Review: Writers in reliability often stress the need for more actual field data. This report presents a compilation of such data covering a fairly good period of time and several kinds of equipment. The data are not broken down to any detail level, but are given at the level of a radar or computer. Apparently no effort was made to see what distribution might be fitted by the data; but in any event the data themselves will be useful to those who are interested only in the numbers per se as well as to those who wish to compare theory with practice.

R68-14150 ASQC 844

ACCELERATED FATIGUE-LIFE TESTING BY THE METHOD OF "TOTAL FRACTURE."

Kh. B. Kordonskii and B. S. Fresin (Rizhskii Institut Inzhenerov Grazhdanskoi Aviatsii, Riga, Latvian SSR).

(Zavodskaia Laboratoriia, vol. 33, Mar. 1967, p. 321-331.) *Industrial Laboratory,* vol. 33, Mar. 1967, p. 382-391. 8 refs. Translation.

(A68-10901)

An equation is proposed for summation of the fatigue failures in a one-shot variation of the load regime. Relying on this equation,

a method is recommended for accelerated fatigue-life tests based on "total fracture" of the specimen; experimental testing of the method has yielded satisfactory results. It is shown that the linear hypothesis of fatigue-failure summation provides a safe assessment of the fatigue life only in cases when the metal is defective. The expenditure of time in conducting the accelerated tests, given an optimum design of the latter, should exhibit a 10- to 15-fold reduction. Author (IAA)

Review: This is a very difficult paper to decipher, perhaps due to the translation. Some of the mathematical notation is difficult to figure out, although given enough time to try and recreate the answers (the method of deriving is not given) one could probably do it. The author claims his method of analysis is much better than linear cumulative damage, although it is difficult to figure out exactly what his method is. Possibly what the author is doing is to run a test at the given small load for a given number of cycles then to raise the load and find how many cycles the specimen lasts at the high load; what comes after that is not clear. It is even difficult to decide whether it is worth deciphering the material or not. In any event, it would probably take someone (who was only reasonable familiar with the situation) a day or two to derive the results and understand them. There are many theories of cumulative damage extant besides the linear theory but no comparison is made with them.

R68-14154 ASQC 844; 713; 760; 775; 817; 833; 851
X-RAY VIDICON ANALYSIS OF ELECTRONIC COMPONENTS.
John J. Lombardi, Jr. and Harvey F. Padden (Grumman Aircraft Engineering Corp., Bethpage, N. Y.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 479–490. 4 refs.
(A68-31437)

Discussion of the use of an X-ray vidicon system for evaluating defects in small electronic components. The defects which are detectable in relays, interconnections, and microcircuits are described and illustrated. Relays can be rotated while under examination to reveal loose particles that can be hidden under internal mechanisms of greater density, the most common defect with relays. The primary failure modes associated with connectors are shorted contacts or terminals. IAA

Review: This excellent paper on X-ray vidicon analysis techniques should be read in conjunction with the papers starting on pages 156, 183, and 501 in the same Transactions. The use of X-ray is not new to the reliability or quality control engineer, but the application is unique and this report is excellent. The use of remote television displays and the use (presumably by remote-controlled manipulators) of changing position to complete the analysis of a potential defect seems new. The examples showing defects in relays, connectors and interconnections, multilayer PC boards, microcircuits, resistors, and capacitors constitute an excellent case-history method of making a technical paper useful and self-explanatory for the neophyte. This paper is highly recommended.

R68-14156 ASQC 844; 760; 775; 833
INFRARED NONDESTRUCTIVE INSPECTION TECHNIQUES.
W. R. Apple (Automation Industries, Inc., Research Laboratory, Infrared Applications Group, Boulder, Colo.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 501–512.
(A68-31439)

Description of active testing, primarily as applied to the evaluation of materials and structures. Active testing consists of applying or removing heat from the test object and measuring temperature variations to determine its internal characteristics. Resolution of defects decreases as defects extend deeper into the test piece because material over the defect diffuses the developed hot spot. IAA

Review: This all-too-short a paper on a very valuable nondestructive testing (NDT) technique is good reading for the busy executive as well as the specialist in NDT. The paper contains a little theory, three applications and some valuable examples of the techniques of application. Infrared technology is relatively new and not practiced by all those who should be using it. The lack of reference to any of the previous work in this field is a shortcoming of this paper. In particular, the work of Riccardo Vanzetti (see, for example, R63-10993, R65-11978, R65-11991, R65-12126, R67-13151, R67-13234, R68-13603, and R68-13713) should be obtained for further reading on the subject. It is also suggested that the reader see pages 183 and 156 in the same Transactions for additional information. The most important piece of information in the paper pertains to the limitation on detecting a defect due to its location and size. The advantages of NDT and the special advantages of infrared are thoroughly explored, and the reader should be acquainted with them before embarking on the use of this NDT method. The illustrations and graphical presentations are of particular interest to the newcomer and manager alike. This paper is recommended to readers of RATR.

R68-14163 ASQC 844
A SYSTEM OF CATEGORIES FOR FAILURE MECHANISM—A TOOL FOR DIRECTING PHYSICS-OF-FAILURE RESEARCH AND REMEDIAL ACTION.
R. H. Norris (General Electric Co., Heat Transfer and Reliability, Schenectady, N. Y.).
In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 769–779. 17 refs.

Five failure categories proposed for planning physics-of-failure research programs are (1) abuse, (2) freaks, (3) variability, (4) extraneous factors of common occurrence, and (5) design deficiencies. Some examples are included for each category, and remedies and identification of causes are discussed. Implications are considered for investigations by laboratories not related to the product manufacturer and for physics-of-failure research by the manufacturer. Mention is made of some previous attempts at categorizing failures. M.W.R.

Review: This is a philosophic paper which attempts to organize the area of failed parts, so that it is easier to know what one is doing. Such papers are helpful because the more we understand what is going on, the easier prediction and analysis are. Allocations to some of the categories are a matter of judgment (just as in sports where many things are a matter of the referee's judgment). An example would be whether to call something Abuse or Design Defect when the rating of the part is very close to the application-conditions. One might wish to have a greater factor of safety in the design and thus would call it a Design Defect or one may wish to feel that the user should be more careful and thus call it Abuse. These categories are an aid to intelligent and practical thinking about the failures. One must be careful that the chosen category is not too narrow a channel, for if it was, effective cures might be defeated. In general, even though one may not wish to act explicitly on the details of the author's program, his ideas are very worth reading.

R68-14167 ASQC 844; 775; 813
METAL PROGRESS, VOL. 94, NO. 2.
Carl Weymueller, ed.
Aug. 1968 190 p.

Nondestructive and mechanical testing are among the major topics covered in this magazine, which also deals with microscopy in metallography, quality-cost interfaces, and other aspects of metallurgy. Organizing a quality control testing program is described in detail; and nondestructive testing is treated in relation to production line application, safety, and testing guidelines. Other articles treat the examination of pressure vessels with radiography, automatic inspection of cold-formed shafts, and testing rocket engine materials. Fourteen experts have reported on innovations and applications of mechanical testing. Other mechanical tests deal with how IBM tests small parts for microhardness and how massive bedplates can ease testing of earth-moving equipment. Operation and use of the scanning electron microscope are reviewed, and automated quantitative microscopy is discussed. In addition to these articles, sections of the magazine are devoted to press releases, letters to the editor, new products, and literature reviews.
M.W.R.

Review: This entire issue is devoted to modern methods of testing and inspection. Four papers are of particular interest to those involved in the reliability discipline (pages 7, 15, 59, and 61). The first paper, which deals with organizing a testing program, is a good one. Since it is written from the point of view of the metallurgist, it naturally emphasizes the many things that metallurgists can do. Metallurgists and designers should work together, although as the author points out, the metallurgist often does not have the data required by the designer for setting realistic tolerances. In addition, the advice about tolerances has to be reconciled with the attitude of the shop. A shop accustomed to working with tolerances which are tighter than necessary may continue to be lax after the tolerances have been broadened to the most desirable limits. Furthermore, many metallurgical variables are notoriously hard to control, especially when costs are paramount. The comments on statistical quality control and working to the center of the specification do not always apply, since there are many reasons for working near one edge of the specification. Even the negative example quoted is not necessarily a bad way of doing things; in fact, it may even approach an optimum policy. The author's comments on the costs of quality are well-taken. It is often difficult to separate out a cost due to the quality control function; the overall costs of the product must be considered when comparing different procedures or materials —almost without regard to which group must contribute most of that cost. Another good point the author makes is that for any quality/reliability program to be effective there must be considerable emphasis on feedback to the process and process controls so that the causes of rejects are eliminated to the extent that is economically feasible. Computers can be used to advantage in many situations but they can also be a sink-hole for the dollars of the unwary. The Letter to the Editor on page 15 deals with a very sensitive area which is quite cavalierly treated by those attempting to devise theories. The concern is with the fact that many materials are not what they are supposed to be. Those who are trying to calculate reliability according to the stress/strength theory of failure and have fitted complicated distributions to the strength data are strongly advised to read this letter, since it shows many of the things which can occur which their conceptual model has not considered. These facts are also of the type which are not stressed, naturally, in papers written by producers. They are not stressed enough in papers written by reliability engineers. The marketplace is not always as sedate and knowable as the advertisements would have us think it is. The third paper of interest to reliability personnel is an editorial which stresses the need for proper planning for reliability and quality control, and does it without getting involved in technical jargon. Thus, it will be of value mainly to those who had not considered these aspects before. Even though it is often true that the presence of many more inspection points on a production line *can* save money, it is not necessarily true that it will. Each case has to be weighed on its own merits to see whether the extra cost of inspection can be recovered by (a) decreased rejects and (b) feedback to eliminate the cause of the original defect. The last paper concerns nondestructive testing on the production line. This is a fairly straightforward conventional paper which lists the common types of nondestructive testing and gives examples of the use of each. It is addressed strictly to the nonspecialist in this area so that he may gain an idea of what each of the techniques might do for his problems.

R68-14173 ASQC 844; 838
California Univ., Livermore. Lawrence Radiation Lab.
OUTPUT POWER CHARACTERISTICS OF THERMIONIC CONVERTER ARRAYS UNDER PARTIAL FAILURE CONDITIONS
James R. Long 24 Apr. 1967 31 p refs Presented at the 2d Intersoc. Energy Conversion Eng. Conf., Miami Beach, Fla., 13-17 Aug. 1967
(Contract W-7405-ENG-48)
(UCRL-70282; CONF-670806-1; N67-35452)

The output characteristics of thermionic converter arrays are determined as a function of interconnection scheme, interconnection resistance, converter failure modes and patterns, and converter characteristics. The arrays consisted of series strings of converters paralleled with each other by resistive interconnections. The use of additional interconnections is considered to form three-dimensional arrays in which edge effects inherent in planar arrays are eliminated. From an analytical point of view, the applicability of a strictly linear model for the converter is improved with three-dimensional arrays. The output of a three-dimensional array under failure conditions is not significantly greater than that of a planar array, and array shape does not have a strong influence on power output. The array reliability is shown to be greater than the converter reliability. A study of the effect of introducing a statistical distribution of converter parameters appears to show less power loss under failure conditions. A study of the effect of matching the load impedance of a failed array shows that the impedance change is small.
Author (NSA)

Review: This paper presents an interesting and useful set of calculations about the behavior of these converters when they are connected in a redundant array. Some of the figures (pictures) are difficult to interpret due to inadequate explanations, but this difficulty is not insurmountable. The author has implicitly assumed that all failure events are statistically independent, that is, the changes in loading caused by an open or short of some of the converters do not affect the remaining lives of the other converters. Some of the author's conclusions are interesting (none of the calculations are given so it would be rather difficult to check on the answers), especially in showing how intuition may easily lead one astray. Anyone who is going to use the results of this paper should very carefully study the restrictions under which the analyses were performed.

85 DEMONSTRATION/MEASUREMENT

R68-14145 ASQC 851; 844

TESTING AND PACKAGING FOR REED RELAY RELIABILITY.

John P. Breickner (Wheelock Signals, Inc., Long Branch, N. J.). *In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967, Proceedings.* Conference sponsored by the Oklahoma State University and the National Association of Relay Manufacturers. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 15–1 to 15–6. 2 refs.

A technique and testing apparatus was developed that resulted in an improved reliability reed relay module, and a low-stress glass resin encapsulant was developed to preserve unencapsulated reliability level. The testing system which permits relays to accumulate 1,100,000 operations, can be used to insure the maintenance of improved reliability in many applications. Using the procedure for early life "miss" testing can eliminate weak relays before they are placed in expensive modules; and the same procedure can be used for in-process testing to preserve reliability during testing. Monitor cycles were found to be sufficient to detect more than 70% of the failures; and with glass resin system, relay life and reliability is expected to approach that of the unencapsulated relay. M.W.R.

Review: This is a case history showing how an unexpected type of field failure was analyzed and cured. The paper proceeds in a straightforward way to describe the relay and the methods used to analyze and cure the problem. This was a reed relay and the important detail which was not considered at first, but turned out to be important, was that the dynamic contact resistance was not the same as the static contact resistance. (Some authors claim that one should always measure dynamic resistance of reed relays.) It is an interesting question whether each problem should have the tremendous detail work put on it that would be necessary so that this kind of difficulty would not arise, or whether it is cheaper to put the ordinary amount of detail work on it and correct the malfunctions when they arise. There are those reliability engineers and experts who feel that the first should always be done, but there are obviously many cases when the second turns out to be the low-cost solution. The author appears to imply that the life test data in Figures 2, 3, and 4 show that there is no indication of a problem. Since some of the units involved have very short life, it is not obvious why there is no problem. In a private communication the author has clarified the problem as follows: "(1) We were comparing the basic relay capability to the poor capability exhibited by the finished module. (2) The early failures shown in Fig. 2, 3, and 4 were early life failures which the run-in by Kaiser could have detected. (Initially, this was a 'standard' device being specified into a high reliability application.) (3) The first goal was to improve module performance to equal that of an unpacked relay. A secondary, and not directly intended, result improved basic relay capability by eliminating these early failures as relays."

R68-14146 ASQC 851; 844

A NEW LIFE TEST SET FOR MINIATURE DRY REED, SEALED CONTACTS.

M. B. Purvis (Bell Telephone Laboratories, Inc., Columbus, Ohio). *In: Annual National Relay Conference, 15th, Oklahoma State University, Stillwater, Okla., April 24, 25, 1967, Proceedings.* Conference sponsored by the Oklahoma State University and the National Association of Relay Manufacturers. Scottsdale, Ariz., National Association of Relay Manufacturers, 1967, p. 17–1 to 7–13. 1 ref.

A life testing set was designed for evaluating the resistance of miniature dry reed, sealed contacts. Maximum contact resistance in a preset interval is recorded on magnetic tape, and as many as 3200 recordings can be made of each of the 256 contact test positions. The test set monitors for sticking contacts at the end of each recording interval, and these data are also placed on the magnetic tape. Timing intervals of the test set, controlled by a logic section, can be varied over a wide range by potentiometer adjustment of delays; and contact drive and current may be varied in amplitude and duration. Operating experience, data reduction, and results for a typical run with the test set are presented. Since initial operation revealed large variations in contact resistance, modifications were made to insure more valid data. Typical output record for a stuck contact is shown, as are life test set results for a group of contacts. M.W.R.

Review: This paper describes a 256 station test set used for life testing miniature, dry reed relays. It will be of interest to those who are involved in life testing relays or other small components as well as to those who are involved in developing their own test-sets or who already have them and wish to compare them with other methods of operation and other experience. The paper naturally gives an enthusiastic account of the machine's behavior.

R68-14151 ASQC 850; 773; 780

PRODUCTION SAFETY MARGIN TESTING FOR ELECTRONIC ASSEMBLIES.

Robert C. Ausec (Martin Marietta Corp., Aerospace Group, Orlando, Fla.).

In: American Society for Quality Control, Annual Technical Conference, 22nd, Philadelphia, Pa., May 6–8, 1968, Transactions. Milwaukee, American Society for Quality Control, Inc., 1968, p. 355–362.

(A68-31428)

The paper covers the results of a reliability confidence test program conducted by Martin Marietta as a second-source producer of the U.S. Army's Shillelagh missile. The purpose of the tests was to demonstrate that a new manufacturing source could maintain the safety margin levels originally demonstrated by the prime contractor. The program measured assembly-level safety margins under elevated climatic and dynamic environments. Launch shock measurements were taken in a unique facility made with surplus aircraft carrier steam catapult sections which provided the proper shock profile at a fraction of the cost of commercial test equipment. The result of the program showed that, with few exceptions, the design and manufacture of the assemblies provided high safety margins against failure under the missile's operational conditions and have demonstrated the success of the U.S. Army Missile Command in setting up a novel program for second-source production of a missile system. Now that this baseline program has been successfully completed, plans are being made for a continuing safety margin sampling program during volume production. Author (IAA)

Review: This paper covers a great deal of ground in a very short space and consequently does not say much except that the company did well on a particular contract where it was required to demonstrate high safety margins. Unfortunately, the term *safety margin* is not defined. It is difficult to see what use Quality Control and Reliability engineers would make of the paper, although a casual reading of it is impressive enough. A quotation from the conclusions of the paper indicates very well the total content of the paper: "The results of the test-to-failure program have demonstrated the feasibility of setting up an alternate producer who is able to build hardware that meets the same reliability requirements met by the prime contractors." In a private communication, the author has commented as follows: "The real intent of the paper was to relate to Quality Control and Reliability engineers that it is possible for a secondary source with part families and test equipment completely divorced from a prime source to demonstrate and maintain the same safety margin levels originally demonstrated by a prime contractor."

SUBJECT INDEX

Typical Subject Index Listing

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TR-3 c84 R68-12733

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The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The category number and *RATR* accession number are used to locate the abstract-review appearing in the abstract section of *RATR*.

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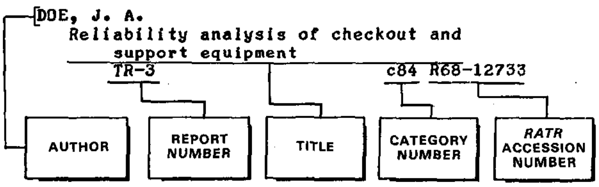

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ANNUAL INDEX

The Contents of
Reliability Abstracts and Technical Reviews
ANNUAL INDEX

This Annual Index is an edited consolidation of the indexes to the individual issues of *Reliability Abstracts and Technical Reviews* for the calendar year 1968 (Volume 8, Numbers 1 through 12). There are four cumulations in this Annual Index. The Subject Index is to assist in scanning or searching the literature on specific topics. The Personal Author Index identifies the publications of specific authors. The Report and Code Index is a listing of the report numbers of items abstracted and reviewed; this index also includes a listing of the American Society for Quality Control codes for identifying the *RATR* accession numbers of items to which the codes have been assigned. A complete listing of these codes appears on the inside back cover of the Annual Index. The Accession Number Index identifies the issues and the categories in which the abstract-reviews appear in Volume 8.

Each entry in this index includes an accession number, e.g., R68-12345, a unique identification number assigned to each abstract-review that was indexed and announced in *RATR* during the year. In addition to the accession number, each entry in the Annual Index includes a 4-digit number (e.g., 10-84). The first two digits identify the issue of *RATR* in which the abstract-review is located. The two digits after the hyphen identify the ASQC category code assigned to the abstract-review.

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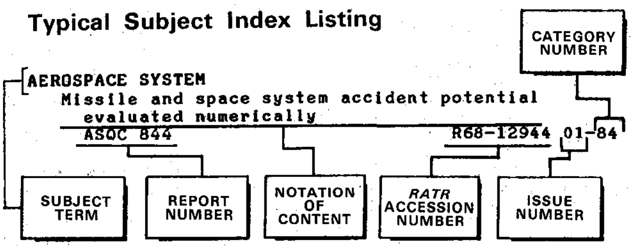
Typical Subject Index Listing



The Notation of Content, rather than the title, is used to provide a more exact description of the subject matter. The *RATR* accession number, the issue number, and the category number are used to locate the abstract-review in the abstract section of an issue of *RATR*. The first two digits following the accession number identify the issue of *RATR*, and the two digits after the hyphen identify the category in which the abstract-review appears.

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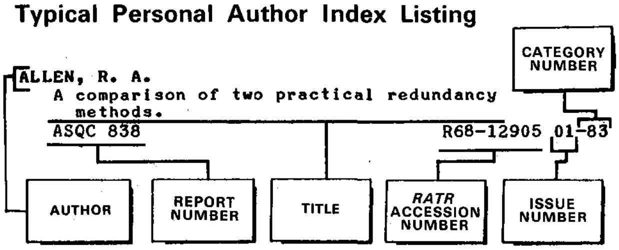
Typical Personal Author Index Listing



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This list may be used to identify the *RATR* accession number of reports covered in this journal. To the right of each report number is the *RATR* accession number, followed by a four-digit number for locating the abstract-review in the abstract section of an issue of *RATR*: the first two digits identify the issue of *RATR*, and the two digits after the hyphen identify the category in which the abstract-review appears. For purposes of this index, AD, N, and A numbers (accession numbers from *TAB*, *STAR*, and *IAA*, respectively) and ASQC code numbers are treated as "report" numbers. Thus, the section of this index listing ASQC codes may be used to identify the *RATR* accession number of the coded abstract-reviews appearing in *RATR*.

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